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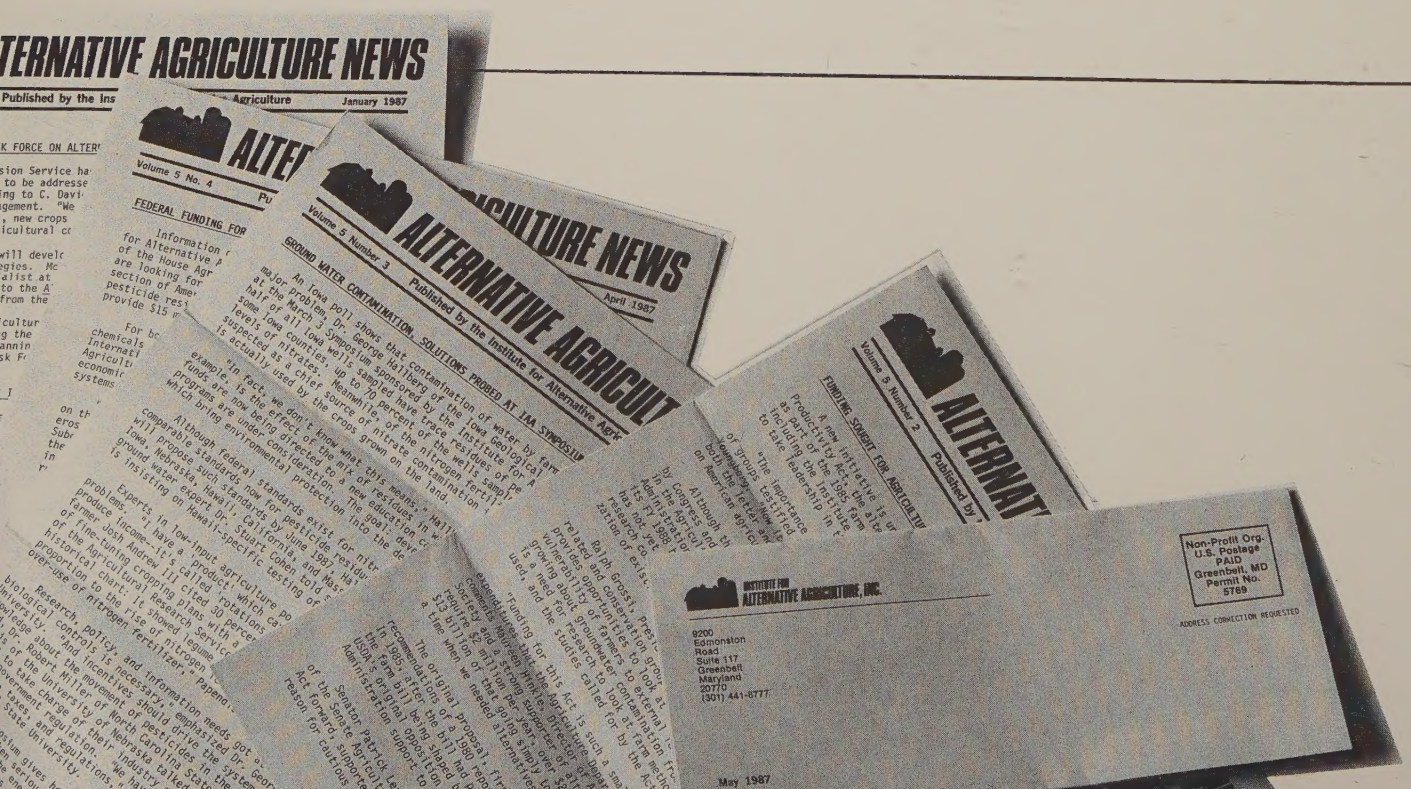
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GROUND WATER CONTAMINATION - SOLUTIONS PROBED AT IAA SYMPOSIUM
An Iowa poll shows that contamination of water by farm
major problem. Dr. George Hallberg of the Iowa Geological
at the March 3 Symposium sponsored by the Institute for A
half of all Iowa wells sampled have trace residues of pe
some Iowa counties, up to 70 percent of the wells sampl
levels of nitrates. Meanwhile, up to 70 percent of the nitrogen fertil
suspected as a chief source of nitrate contamination
is actually used by the crops grown on the land.
"In fact, we don't know what this means," Hall
examples. Is the effect of the pesticide residues in
funds are now being directed to a new education pr
programs are under consideration. The education into the dev
which bring environmental protection
Although federal standards exist for nitr
comparable standards now for pesticide residu
will propose such standards by June 1987. Hal
Iowa, Nebraska, Hawaii, California and Mass
ground water experts Dr. Stuart Cohen told
is insisting on Hawaii-specific testing of
Experts in low-input agriculture po
problems. "I have a product which ca
produce income-it's called rotations
of fine-tuning cropping plans with a
historical chart. It showed 30 perce
proportion to the rise of nitrogen
over-use of nitrogen fertilizer."
Research, policy and information needs got o
biological controls is necessary, emphasized Dr. Geo
University. "And incentives should drive the syste
knowledge about the movement of pesticides in the
Research or Robert Miller of the University of Nebraska talked
to take charge of their industry
government regulation. We ha
Extension and state universities
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Institute Information

The Institute for Alternative Agriculture is a nonprofit, tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low-cost, resource-conserving and environmentally-sound farming methods. It works closely with producer groups, public research and education institutions, and government agencies in promoting a sustainable agriculture system.

Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

The cover photo shows a test/demonstration area in the Sudan-Sahelian Zone of Niger, West Africa, and emphasizes the importance of proper utilization of crop residues on land to improve the tilth, fertility, productivity and long-term sustainability of agricultural soils. The standing crop is pearl millet (*Pennisetum glaucum* L.) which is the dominant food grain crop that is grown, largely on marginal (sandy and infertile) soils, throughout this drought-prone, semiarid region. The study was conducted cooperatively by scientists from USDA, USAID and Texas A&M, with invaluable participation by villagers, both young and old, who maintained the area and ensured that the goats and other ruminant animals were excluded during the test period. Photo provided by Dr. J.F. Parr, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland.

OPINION

Rethinking agricultural education

Kamyar Enshayan

Is it possible to have public agricultural colleges that promote the establishment and maintenance of a permanent, sound and prosperous agriculture and rural life, as mandated by the acts establishing the land-grant colleges (1862), the experiment station system (1887), and Cooperative Extension (1914)? If so, what would they be like? What kinds of educational programs would they offer students to create an enduring agriculture and avoid the prevailing tolerance for our existing system of food and agriculture, which demeans rural people and degrades the land?

Basic Assumptions

Recent investigations into cognition and learning can provide new conceptual frameworks for agricultural education. It is now clear that "knowledge is situated, being in part a product of the activity, context, and culture in which it is developed and used" (Brown et al., 1989). This implies that what is learned cannot be separated from how or where it is learned. One implication is that what is learned by the students and faculty in most agricultural schools is fundamentally different from what is learned in farm communities and rural places. The former learning, for the most part, is embedded in the culture of departmentalized thinking, a "reductionistic-science-is-*the*-answer" mindset, refereed journals, and an unhealthy sense of know-it-allness. The latter learning, on the other hand, is rooted in experience, years of trial and error, community, economy, and familiarity with a particular landscape.

Most agricultural colleges think of themselves as "custodians and preservers of knowledge. This creates the image of knowledge as a commodity that can be stored or warehoused and then dispensed or given (usually by a lecture) to a recipient (a student)" (Ison, 1990). Research in learning challenges this attitude and practice. We are now realizing that knowledge cannot just be handed over or transmitted, but must be built anew by each learner with a supportive teacher who leads from behind (Wells, 1989; McCutcheon and Jung, 1990). We now know that farmers and students are participants and active constructors of their own knowledge (Chambers et al., 1989; Haverkort et al., 1991).

Agricultural education for a sustainable agriculture should emphasize learning rather than teaching. A rich learning environment for agriculture faculty and students alike has to involve all of agriculture: the landscape, farms, farmers, traditions, and culture. If we begin to see that "research is not a process of proving something, but a process of discovering and learning" (Ray, 1987), we may see problem solving, thinking, learning, research, and discovery as the same process. This rethinking would entail abandoning our way of viewing teaching, research and extension as separate.

Specific Programs

Here are a few ideas for agricultural schools, whether private or public, that wish to create a learning environment for a sustainable agriculture:

History of agriculture. This theme is rarely included in the courses of agricultural schools, but it is so crucial for all of us to learn from our agricultural past.

Key ideas in conservation and sustainable agriculture. Students of agriculture need to know who has said what. Students and faculty must be aware of the key ideas presented by anthropologists, historians, poets, philosophers, conservationists and many past and contemporary scholars who have outlined agriculture's problems and prospects.

Farmers-in-residence. In law schools and medical schools, practitioners are invited to work with students, to teach, and to share their experiences. We ought to do the same in agricultural schools.

Farm apprenticeships. The best place to learn farming is on the farm. Ideally, it will greatly benefit both the farmer and the apprentice.

Community-building apprenticeships. Agriculture students should spend time as interns with the key rural development and sustainable agriculture organizations in their region.

Agricultural ecology. Students should undertake a series of studies dealing with landscape ecology, agricultural energy, soil ecology, nutrient cycling, recycling and other fundamentals of ecology.

Faculty-student farm. Sustainable agriculture education in universities must, among other things, be formulated around a faculty/student-run working farm. Both faculty and students should be involved in the labor and planning. Working on such a farm can inspire important research questions and provide a firsthand opportunity for students and faculty to put into practice their ideas for ecological soundness, soil improvement and economic vitality.

Direct involvement in the regional food economy. The faculty/student-run farm should participate in local markets so that

A preliminary version of this article was published in *Organic Farmer*, Fall, 1992.

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students and faculty think through and understand how agricultural policies affect the local and international food economy.

Exploring the appropriate balance between food self-reliance and trade. Why should Ohio's landscape be covered with corn and soybeans for export, with their accompanying soil erosion scars, while we import tasteless food from California and other distant places? How much food trade is OK? These and many other questions are extremely important for everyone to think through.

Forums on current and long-term agricultural issues/problems. There should be frequent public forums and debates held at agricultural schools exploring important current issues such as the Farm Bill, GATT, roots of rural decline, rural-city partnership, etc. Agricultural schools should be facilitators for such debate and dialogues.

Understanding the human element of agriculture. Agriculture involves more than soil chemistry equations and agricultural economics; it involves people, cultural traditions, stewardship ethics, communities, stories, memories. Agricultural education for sustainability should weave these together.

Until now, these educational elements have been provided mostly through private non-profit sustainable agriculture research and education institutions, rural development organizations, and farmer-run associations. The sustainable agriculture programs in agricultural universities, liberal arts colleges, and other agricultural institutions are growing in number and maturity, and have a wealth of talents to create learning environments for a sustainable agriculture.

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UPCOMING EVENTS

February through March 18, sustainable agriculture field days will be held throughout Wisconsin; for details, contact Wisconsin Dept. of Agriculture, Trade and Consumer Protection, 801 W. Badger Rd., PO Box 8911, Madison, WI 53709-8911; (608)262-6429 or (608)625-2602.

February 18-21, the second *Organic Farm Fresh Table Top Exhibit* will be held in conjunction with Natural Products Expo West '93 in Anaheim, CA; contact Steven Hoffman, New Hope Communications, 1301 Spruce St., Boulder, CO 80302; (303)939-8440.

February 23-25, *Silage Production from Seed to Animal*, sponsored by the Northeast Regional Agricultural Engineering Service, will be held in Syracuse, N.Y; contact NRAES, 152 Riley-Robb Hall, Cooperative Extension, Ithaca, N.Y. 14853-5701; (607)255-7654.

February 23-26, *Preserving Our Environment: The Race Is On*, the 24th Annual International Erosion Control Association conference and trade exposition, will be held in Indianapolis, IN; contact IECA, P.O. Box 4904, Steamboat Springs, CO 80477-4904; (303)879-3010.

February 26-27, *An American Farmer Can Feed a Nation, But Can He Feed His Family?*, a sustainable agriculture conference sponsored by Central Colorado Water Conservancy District Sustainable Agriculture Project, will be held in Greeley, CO; contact CCWCD, 3209 West 28th St., Greeley, CO 80631; (303)330-4540.

February 27, the annual meeting of the Nebraska Sustainable Agriculture Society will be held at Central Community College—Platte Campus near Columbus, NE; contact NSAS, Box 736, Hartington, NE 68739; (402)254-2289.

February 27-28, the 14th annual *Ohio Organic Conference* will be held at the Agricultural Technical Institute, Wooster, OH; contact Ohio Ecological Food and Farm Association, 65 Plymouth St., Plymouth, OH 44865; (419)687-7665.

March 1, *Alternative Agriculture Policy: A New Time to Choose*, the 10th annual conference of the Institute for Alternative Agriculture, will be held in Washington, D.C.; contact the IAA, 9200 Edmonston Road, #117, Greenbelt, MD 20770; (301)441-8777.

March 14-16, *The Next Generation of U.S. Agricultural Conservation Policy*, sponsored by the Soil and Water Conservation Society, will be held in Kansas City, MO; contact SWCS, 7515 Northeast Ankeny Road, Ankeny, IA 50021-9764; 1-800-THE SOIL.

Economic and environmental considerations for nitrogen management in the mid-Atlantic coastal plain

Patricia E. Norris and Leonard A. Shabman

Abstract. *A case study in eastern Virginia provides evidence that both environmental and farm profit goals may be satisfied by alternative nitrogen (N) management strategies for grain production. We used a linear programming framework with an N mass balance model to calculate returns from several options for providing N to crops. Replacing single applications of inorganic N fertilizer with split applications or with additions of organic N were found to reduce the potential for N loss from cropland and to increase net returns. For some N management strategies, however, adoption may require financial and educational assistance. As a result, water quality policies may benefit by including such incentives.*

Key words: rotations, organic fertilizer, poultry litter, net returns, mass balance, water quality

Substituting organic sources of nitrogen (N) for inorganic N fertilizer and changing the timing of inorganic N applications have been suggested as ways to reduce pollution of ground and surface water (Papendick et al., 1987). This paper reports on the relative on-farm profitability of alternative N management systems and their potential for reducing N pollution, taking account of N carryover between years and the long-term buildup in soil fertility from organic N sources. We also evaluate policies that might encourage alternative on-farm N management systems. To provide necessary background, a simple mass balance model of N in agricultural soils is described. We then integrate this model into a linear programming framework to evaluate the on-farm financial returns and potential water quality improvement from alternative N management strategies for a case study area in eastern Virginia. In drawing conclusions about policy alternatives, we rely on both the model and a mail survey of farm operators in the case study area.

Patricia E. Norris is Assistant Professor, Department of Agricultural Economics, Oklahoma State University, Stillwater, OK 74078; Leonard A. Shabman is Professor, Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Nitrogen Management in Crop Production: A Mass Balance Perspective

Modeling N management systems requires recognition that N is conserved in the various transformations and biological processes of the soil-plant production system (Legg and Meisenger, 1982). Figure 1 illustrates a simplified N mass balance model in agricultural soils. There are three general sources of plant available N, that is, inorganic N that is suitable for uptake by crops. Source (1) is mineralization of N from the decomposition of organic matter in the soil, including previous years' crop residues. Organic N in the soil will increase as additional organic matter is introduced, and mineralization will release increasing amounts of inorganic N over time. The decay rate of the organic matter depends on its C:N ratio and on soil temperature and moisture. Warmth and moisture will accelerate decay. Source (2) of plant available N is inorganic and organic N fertilizers. At present, most fertilizer is inorganic (Papendick et al., 1987). Organic N can be added as crop residues, livestock manure, sewage sludge, and green manure crops. Organic N is not available to plants until the organic matter has decomposed. However, organic materials also can contain some plant available N. Source (3) of N is natural additions, including biological N fixation by legume crops and N in precipitation.

In the mass balance model, available N (Box 4) goes into one of three categories: immobilized N, N removed in the harvested crop, and N lost from the system. Some plant available N is immobilized (taken up by microorganisms and bound in cell structure) and is retained in the soil. This is the movement in Figure 1 from Box 4 to Box 1. Immobilized N is not lost from the agricultural system, but it is not available to plants until it is mineralized. N immobilized in the soil organic matter may come from the applied inorganic N fertilizers or from N previously mineralized from decomposing crop residues or manures. Most immobilized N eventually will be released when organic matter decomposes.

For water quality management, the central concern is inorganic N that is lost from cropland by leaching, erosion and runoff, a portion of the N in Box 6. Following the terminology used in the envi-

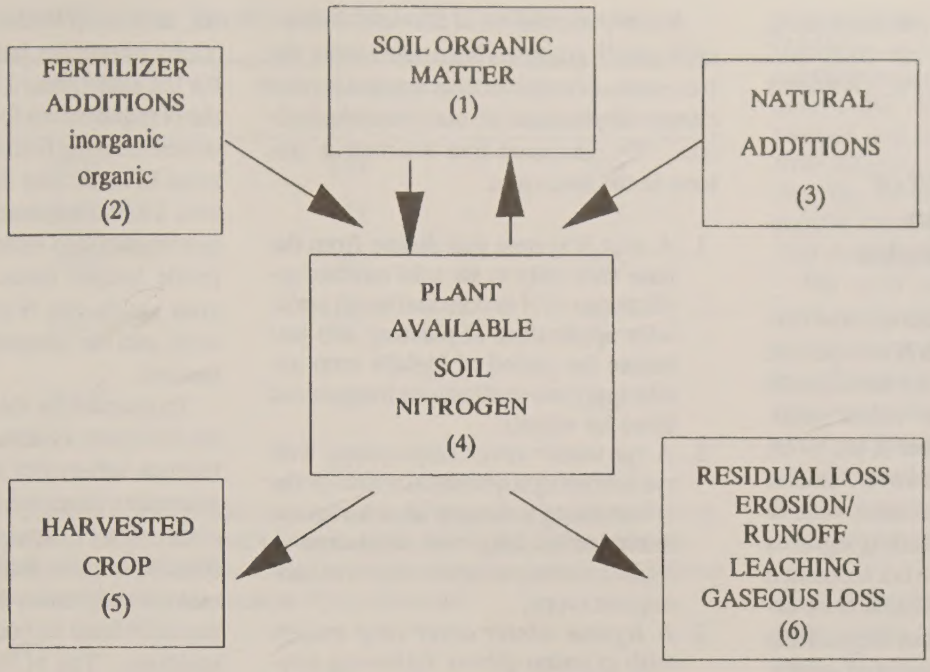
SOIL ORGANIC MATTER (1)
FERTILIZER ADDITIONS inorganic organic (2)
NATURAL ADDITIONS (3)
PLANT AVAILABLE SOIL NITROGEN (4)
HARVESTED CROP (5)
RESIDUAL LOSS EROSION/ RUNOFF LEACHING GASEOUS LOSS (6)

Figure 1. Single-period mass balance model of nitrogen transport in agricultural soils.

ronmental economics literature, we call Box 6 *residual* N. In the materials balance model, residuals are the by-products of production, or *discommodities*, which must dissipate into the environment (Kneese et al., 1970). (Soil scientists typically use the term *residual* for N that is immobilized or otherwise stored in the soil [Carter et al., 1974; Onken et al., 1985]. However, we denote that N as N *carryover*.)

A time dimension is implicit in the mass balance model of the system. Inorganic N additions (Box 2) are immediately available to plants. Also, nitrate can be lost immediately to air or water (Keeney, 1983). Organic sources of N, Box 1 or Box 2 in Figure 1, decay over several years, with small amounts of N becoming available to plants each year (Bartholomew, 1965; Fox and Piekielek, 1988). For a given organic N addition, approximately half the N is mineralized (becomes plant available) in the first year, but this release occurs gradually during the growing season (Bartholomew, 1965; Givens, 1987). An on-farm N management system that closely matches the availability of inorganic N from all sources to the rate at which plants use it will minimize residual N. This requires the farmer to plan carefully for the amount, timing and form of N applied, and to account for existing N in soil organic matter.

Researchers in Virginia have found that applying fertilizers near the time of wheat's greatest vegetative growth, or making several applications timed to the crop's needs, can increase the crop's uptake of N (Gravelle et al., 1988). For example, for the first 4 to 5 months of growth, wheat needs only 15 to 20% of the total N used during the growing season. Uptake increases rapidly after about 5 months (Alley et al., 1987). In a year of typical rainfall, applying a small amount of N to aid establishment of the crop and side- or top-dressing the remainder later will avoid the accumulation of nitrate that may be subject to leaching, runoff or denitrification before plants remove it.

Another option for timing available N to plant requirements is to use organic sources of N, including green manures, animal manures, and sewage sludges. When applied at rates consistent with crop requirements, the slow decomposition of the organic matter and release of N over the growing season will be matched to the crop's needs, which avoids an accumulation of nitrates subject to leaching. Organic sources can provide enough inorganic N over the season to satisfy a large part of the crop's N needs (Voss and Shrader, 1984; Klausner and Bouldin, 1985; Hargrove, 1986). Organic N sources can be supplemented with inorganic N if necessary.

Organic sources of N will provide N to future crops as the organic matter decomposes over several growing seasons. As organic matter in the soil system is increased, the need for any external N will decline. Continued use of organic N has cumulative effects that often are measurable in the second and third season after incorporation (Bartholomew, 1965). The danger of over-winter leaching of nitrates is eliminated when only organic N remains in the soil over winter, because the release of inorganic N stops when soil temperature drops below 4°C (Brady, 1974). Decay resumes in the spring when soil temperature rises. Where soil temperatures do not drop low enough to arrest mineralization, a winter cover crop can be an important sink for mineralized organic N.

This mass balance model does not calculate the amount of residual N that ultimately reaches surface or groundwater. Rather, it only computes how much inorganic N is not used by crops or stored in the soil, indicating potential contamination problems (the residual N reported in this paper). With appropriate climatic and geological data, however, the transport and

fate of residual N could be predicted using simulation models such as GLEAMS (Leonard et al., 1987) or EPIC (Williams et al., 1984).

Economic Modeling of Alternative Nitrogen Management Strategies

Researchers have realized that the carryover of inorganic fertilizer N is important for determining appropriate fertilization rates in regions where over-winter leaching is not significant (Stauber et al., 1975; Segarra et al., 1988). However, studies that have examined the economic returns to organic sources of N, including legumes and livestock manures, have not accounted for the N that becomes available from organic matter mineralization beyond the year of application (Helmers et al., 1986; Goldstein and Young, 1987; Dobbs et al., 1988). The mass balance perspective, recognizing the time dimension, uses multiple periods to model the economic returns to N management alternatives. As a result, adoption of organic N sources can be considered a capital investment that yields a return over time. Thus, the net returns from alternative N management systems should be compared in present value terms.

For this study, we estimated the present value of net returns over variable costs of N management strategies for a 202.5 hectare (500 acre) grain farm in a region of sandy, well drained soils in eastern Virginia. The production systems evaluated encompass the crop rotation, tillage practices, soil conservation practices, pest control activities, and fertilization. For each production system, we assumed that corn is planted using reduced tillage, consisting of chisel plowing and disking. Small grains (wheat and barley) are planted conventionally, and double-cropped soybeans are no-tilled into small grain stubble. All planting is done on the contour. Pest control is based on scouting and target spraying, and nutrients other than N are applied according to soil test recommendations for a typical soil in the study area. All variable costs of production, excluding N and labor, were calculated for a composite hectare of each system that reflects the proportion of each crop in the rotation.

A two-year rotation of corn and double-crop small grain/soybean represents the base case. N requirements are met by one custom application of commercial fertilizer. We compared four alternative systems to the base case:

1. A *split N* system that differs from the base case only in its split custom applications of N to corn and small grain, with application at planting and just before the period of highest crop uptake rate (two applications for corn and three for wheat);
2. A *rye winter cover crop* system with rye following soybeans as a sink for the N remaining in the soil after harvest to minimize leaching over winter and as a green manure to return that N to subsequent crops;
3. A *legume winter cover crop* system with crimson clover following soybeans to serve as both an N sink during the winter and a source of N. (A shorter season soybean is assumed for this system so that soybeans are harvested and clover is sown in mid-September);
4. A *poultry litter* system with dry broiler litter as a source of N, P and K for crops.

At the time of the study, an experimental program was underway to transport poultry litter from the poultry producing region of Virginia to the grain producing area of eastern Virginia. The program used grain trucks, which haul grain from eastern Virginia approximately 275 km to the poultry region and would otherwise return empty, to transport poultry litter to eastern Virginia. It encouraged several grain producers to try the litter. The costs of the "backhauling project" were subsidized by the state government. However, this subsidy was not included in the shipping and handling costs in the analysis.

Multi-period linear programming models were developed to compute net returns and N residuals from alternative N management strategies. The linear programming framework provides an organized, straightforward approach for solving a complex system of equations (Paris, 1990). Model activities include the crop production systems, alternative sources of N, and labor. The model calculates the present value of net returns from each crop production system, subject to a fixed yield target for each crop in the prescribed rotations. Yield targets are based on average yields for the study area. Using the yield targets, the N requirement for each crop was determined from the N content of the crop's biomass (Tisdale and Nelson, 1966; Gilbertson, 1979; Donahue et al., 1984). N requirements also were calculated on a composite hectare basis. Table 1 shows the crop yields and N requirements for each crop, and the composition of a composite hectare.

To account for the N transformations in the soil-plant system, we constructed an N balance sub-model within the linear programming framework. The sub-model accounts for N inputs from inorganic fertilizers, organic fertilizers (legume green manure and poultry litter), and mineralization of N from soil organic matter and crop residues. The N balance submodel requires coefficients to account for the plant available N from the various sources, the N in the harvested crop, and carryover and residual N. The model keeps an account of residual N lost from the production system in each period. (N movement to surface or groundwater, once it has washed from the field or moved below the root zone, may occur over an extended period. However, the model does not cover fate and transport.) These allocations depend upon N source, crops grown, and weather. We assumed average rainfall and temperature levels for the study area. Technical coefficients for the N balance submodel were based on agronomic and engineering research reported in the literature, as follows:

1. Of the inorganic N fertilizer applied in a single application at planting, 60% is available to satisfy crop needs (Keeney, 1982).
2. Of the inorganic N fertilizer applied in a split application, 80% is available to satisfy crop needs (Alley et al., 1987; Gravelle et al., 1988).
3. When a legume green manure is used, 78% of the organic N mineralizes and 60% is available to the crop in the first year. Ten percent becomes available each year for the next two years, and 5% in the fourth year (Bartholomew, 1965). Clover contains 112 kg/ha N when it is disked under (LaRue and Patterson, 1981; Hargrove, 1986).
4. When poultry litter is incorporated into the soil, 90% of the inorganic N is

Table 1. Crop Yields and Nitrogen Requirements for Individual Crops and for Composite Hectare

Crop	Yield (kg/ha)	N requirement (kg/ha)	Hectares per Composite Hectare[1]
Corn	6271	154	.500
Wheat	2688	75	.275
Barley	3225	83	.225
Soybeans (d.c. wheat)	1680[2]	154	.275
Soybeans (d.c.barley)	1814[2]	167	.225
Composite		197	

[1] A composite hectare consists of 1/2 ha corn and 1/2 ha small grain/soybean double crop. This corresponds to half of cropland in each crop in each year of the 2 year rotation.
[2] A 10% yield reduction occurs with shorter season soybeans in the Legume Winter Cover System, and there is an associated reduction in N requirements.

available to the crop. Fifty percent of the organic N also is available in the year of application. In the next four years, the fraction of initial organic N application that becomes available is 12, 5, 2 and 2%, respectively (Gilbertson, 1979). The dry broiler litter in the model contains 29 kg total N, 21 kg P_2O_5, and 17 kg K_2O per Mg (average results of Virginia Tech 1988 broiler litter analyses).

5. For each application of inorganic fertilizer, a certain amount is immobilized (see discussion below). A small amount of this immobilized N is mineralized in the following year (Keeney, 1986). Also, soil organic matter releases a given amount of plant available N. Soil organic matter generally contains about 5% N. Approximately 3% of the total N in the organic matter will become available to the crop during an average growing season (Ankerman and Large, 1987).
6. Legume crops meet their N requirements through biological N fixation (Nutman, 1965).
7. The amount of N removed in the harvested portion of the crop is computed from the assumed yield. We assume that this amount is proportional to yield (that is, N content is constant) (Fried et al., 1976; D.E. Brann, Dept. of Agronomy, Virginia Polytechnic Institute and State Univ., personal communication, 1987).
8. Of all N additions, 12 to 15% (depending on the N source) is immobilized in the soil. The later release of part of that N is described in item 5 above (Keeney, 1986).
9. N not accounted for by crop use, immobilization, and the carryover of organic N is assumed lost by leaching, runoff or denitrification (Allison, 1965).

(For further details, consult Gilbertson [1979], Bartholomew [1965], Tisdale and Nelson [1966] and LaRue and Patterson [1981].) Altering the N balance model coefficients for the climatic regime and soil conditions will change the modeled amount and timing of plant available N from different sources. In turn, this means that the calculated annual returns and present values for production systems can vary among areas.

For each production system, returns were calculated for a ten-year period. As a result, the present value of net returns and the N residuals from each system can be compared. We used a discount rate of 5% to reflect the real returns to capital in agriculture over the long run (Barry, 1980). Inflation was excluded, since 1988 prices were used for all years.

Net Returns to Alternative Nitrogen Management Strategies

Figure 2 shows the annual net returns to land, management and capital in 1988 dollars for each system. The results do not represent total farm income, since fixed costs and government payments are not included. Government payments are excluded because program eligibility and participation are the same for all systems considered.

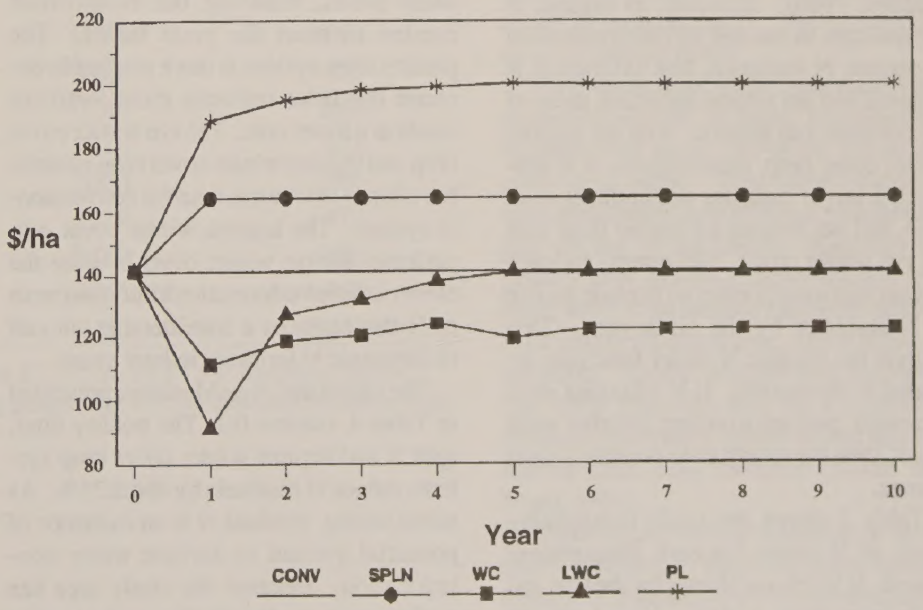

Figure 2. Annual net returns from alternative nitrogen management systems, in current dollars, over ten years.

Net returns for the conventional system are constant across the ten-year period and serve as a benchmark for comparing returns for alternative systems. Because the split N system requires less inorganic N fertilizer to meet the fixed yield target, it has higher annual net returns. Similarly, net returns from the poultry litter system are immediately higher, since all external N needs are met by the litter. Net returns increase over time as organic N accumulates and less poultry litter is required to meet crop needs. In addition, all P requirements and most K requirements are met by the poultry litter applications. P application for this system exceeded crop requirements by 5 to 15 kg/ha annually. This excess was not considered important enough to limit poultry litter application rates, since contour planting and conservation tillage should control P losses.

The net returns with rye and legume winter cover crops at first are lower than in the base case. Because the winter cover crops are planted following soybeans in year 1, but N benefits are not available until the following corn growing season, both the seeding costs for the cover crop and the usual inorganic N fertilizer costs are incurred in the first year. This added cost, with its resulting reduction in income, is part of the transition costs that farmers often experience when converting to an alternative production system (Dabbert and Madden, 1986). However, as organic N accumulates in the soil and mineralization of organic N increases, less external N is required and net returns approach those of the conventional system. With the legume winter cover crop, more organic N is supplied, a larger quantity accumulates over time, and net returns are higher than with the rye winter cover. Net returns for each system that incorporates an organic source of N stabilize by the sixth year. This reflects the organic N decay functions included in the models. If N additions were increased, perhaps to reflect a higher yield target, then the steady state position would change.

Table 2 shows the profit maximizing levels of N inputs for each management system. N levels are shown for the first and tenth years of the analysis. Year 1 reflects the initial inorganic N fertilizer requirements of the systems incorporating organic matter. Year 10 reflects the steady state N levels from each source; the carryover of organic N reduces inorganic N requirements. Table 3 presents the production costs, including N costs, for each system.

Table 2. Nitrogen inputs (kg/ha) to alternative nitrogen management systems, Years 1 and 10.[1]

	Inorganic Fertilizer N[2]		N from Organic Matter[3]		N from Boiler Litter[4]	
	Yr 1	Yr 10	Yr 1	Yr 10	Yr 1	Yr 10
Conventional	144	144	51	51		
Split Nitrogen	109	109	50	50		
Rye Winter Cover	144	127	51	61		
Legume Winter Cover	144	65	51	97		
Poultry Litter	5	0	48	48	86	89

[1] Not including N fixation by soybeans of 59 kg/ha for each system.
[2] Total inorganic N applied. 80% used by crops in split nitrogen system; 60% used by crops in all other systems.
[3] Includes mineralized N used by crops from crop residues, soil organic matter, immobilized inorganic fertilizer, and green manures where applicable.
[4] Includes N used by crops.

Table 4, column (a) reports the present value of net returns per hectare for each production system. The split N system is more profitable than the conventional system because N applications are timed to plant needs, reducing the N fertilizer needed to meet the yield target. The poultry litter system is more profitable because the litter replaces most fertilizer needs at a lower cost. The rye winter cover crop and legume winter cover crop systems have lower net returns than the conventional system. The legume winter cover outperforms the rye winter cover because the clover crop introduces an additional source of N that replaces a considerable amount of inorganic N fertilizer in later years.

The calculated N residuals are presented in Table 4, column (c). The poultry litter, split N and legume winter cover crop systems reduce N residuals by about 35%. As noted earlier, residual N is an indicator of potential ground or surface water contamination. Because the study area has well drained, sandy soils that are especially susceptible to leaching of N, these residual changes are an approximation of changes in N pollution loadings. Compared to the conventional system, all the alternatives reduce residual N. Furthermore, net returns for two of the four alternative systems exceed those for the conventional practice. These results suggest that environmental and farm profit goals are compatible.

Alternative Policy Approaches for Reducing N Residuals

The split N, legume winter cover, and poultry litter systems offer equivalent reductions in N residuals and would help to improve water quality. The rye winter cover crop offers less reduction in N residuals (see Table 4, column c). However, a financial loss was calculated for producers who adopt either cover crop system, so there is no reason to expect their widespread adoption. Conversely, the results of the economic model do suggest profit opportunities in switching from the conventional system to the split N and poultry litter alternatives. These results motivated us to analyze the case study area further by a survey of farm operators.

To learn the current use of the alternative N management strategies in the study area, a sample of 1,127 (one-third of the

Table 3. Operating costs ($/ha) for alternative N management systems.[1]

	Machinery, seed, P and K[2] (annual)	Hired Labor[3] (annual)	Inorganic N fertilizer[4]		Broiler Litter[5]		Additional K fertilizer	
			Yr 1	Yr 10	Yr 1	Yr 10	Yr 1	Yr 10
Conventional	333	6	85	85				
Split Nitrogen	333	6	64	64				
Rye Winter Cover	355	11	85	75				
Legume Winter Cover	360	9	85	38				
Poultry Litter	257	8	3	0	101	88	13	16

[1] Includes 10.5% interest on operating expenses.
[2] P_2O_5 and K_2O are custom applied at $0.62 and $0.35/kg, respectively.
[3] Hired labor cost is $4.00/hr.
[4] Inorganic N is custom applied at $0.59/kg.
[5] Broiler litter cost to farmer is $22.32/Mg. Cost per Mg calculated as follows:

Broker purchases litter from poultry producer	$5.51
Broker cost for loading litter	1.65
Broker cost for transporting litter (275 km, 18 Mg capacity truck)	14.06
Profit margin for broker	1.10
Cost to farmer for litter delivered	$22.32

Table 4. Present value of net returns and total nitrogen residuals over ten years from alternative nitrogen management systems, 202.5 ha.[1]

	(a) Present Value of Net Returns ($/ha)	(b) Present Value of Net Returns with $0.22/kg Tax ($/ha)	(c) Nitrogen Residuals (kg/ha)
Conventional	1147	862	725
	(100)[2]	(100)	(100)
Split Nitrogen	1335	1120	480
	(116)	(130)	(66)
Rye Winter Cover	974	716	623
	(85)	(83)	(86)
Legume Winter Cover	1069	914	477
	(93)	(106)	(66)
Poultry Litter	1063	1063	467
	(140)	(186)	(64)

[1] Crop prices per bushel are: corn $2.20; wheat $2.73; barley $1.94; soybeans $6.24.
[2] Number in parentheses is an index indicating percentage of conventional system results for each alternative system.

listed farmland owners) was drawn from county Agricultural Stabilization and Conservation Service records. All were mailed a survey form, with follow-up mailings according to Dillman's (1978) suggestions; 572 forms were returned, of which 112 were from people who identified themselves as farm operators. The 112 responses are reported below.

Forty-eight respondents split their N applications on corn; of these, 14 also used a legume cover crop. Ten of the 112 used a cover crop alone. That some producers have switched to split N offers general support for the model results. Although the poultry litter system is economically feasible, there is no assured supply of poultry litter within the study area, which limits its adoption. Recent analysis has suggested that litter transport may be a profitable business enterprise, which means that the use of litter may increase (Bosch and Napit, 1992).

Encouraging further adoption of alternative systems to improve water quality (reduce N residuals) may be possible using

economic incentives (Harrington et al., 1985). For example, a tax on N fertilizer might reduce its use and encourage a switch to alternative N sources. Conversely, a direct subsidy might be given for using an alternative. In fact, a subsidy for planting legume cover crops was available in the area when the survey was conducted, which may explain some cover crop use by respondents (Virginia Division of Soil and Water Conservation, 1988).

Table 4, column b, reports the net returns to each N management strategy with a tax on inorganic fertilizer N of $0.22/kg ($0.10/lb), or about a 1/3 price increase. The economic effects of the tax can be judged by comparing columns a and b in Table 4. The relative profitability of the alternative systems that use less inorganic N increases with the tax. Relative profitability of the legume winter cover crop system increases, from slightly less profitable than the conventional system to slightly more so.

Table 5 shows the number of years that an annual direct cash subsidy of $61.75/ha ($25.00/acre) would be required to make the net returns from the cover crop systems exceed the conventional system's. This payment would make the legume winter cover system more profitable than the conventional system after only two years. Payments would be required each year for three years to make the rye winter cover crop more profitable. The subsidy need not last long to change the relative net returns, because it is needed only to overcome the initial decline in returns, or transition cost, illustrated in Figure 2.

The model results suggest that a tax or subsidy could encourage a shift to alternative N systems. To consider this possibility further, the 54 respondents to the survey who were not using either split N or a legume winter cover were asked how they would respond to these policies. First, these farmers were asked if a $0.10/lb increase in the price of N fertilizer would encourage them to use an alternative system. They were then asked a similar question about a $25/acre subsidy. The results reported in Table 6 suggest that a substantial, but not complete, shift would occur. This may seem surprising, given that the model found either incentive enough to make the alternative more profitable.

Table 5. Present value ($/ha) of net returns from cover crop nitrogen management systems with $61.75/ha direct cash subsidy.

Years of Payment	Rye Winter Cover	Legume Winter Cover
0	974	1069
1	1035	1131
2	1094	1190[1]
3	1150[1]	1246
4	1204	1299
5	1254	1350

[1] Conventional system total net returns ($1146.85) exceeded by providing subsidy each year for three years for rye winter cover system and each year for two years for legume winter cover system.

Table 6. Percent of survey respondents not currently using alternative systems who would be encouraged to switch from conventional system with tax or subsidy (n=54).

Alternative System	$0.22/kg Tax on Inorganic Fertilizer N	$61.75/ha Direct Subsidy
Split Nitrogen	44%	68%
Legume Winter Cover	39%	78%
Poultry Litter	34%	71%

Of course, the model's costs and simple profit maximizing objective function may not apply to all farm operators in the area. For example, producers who want to avoid risk may not adopt an alternative production system if they are not familiar with it. The role of information in the adoption decision must also be considered when comparing the model and survey results. The model's technical coefficients represent the best current scientific understanding of how these systems provide N to crops. It is unrealistic to expect such information to be available to, and used by, operators accustomed to conventional fertilization practices.

Besides not having access to the information incorporated in the model, producers may not even be informed about the basic relationships that characterize the mass balance model. If so, they will not recognize that the alternative systems even are possible as substitutes for conventional systems. They then would not be responsive to price changes that are expected to induce the adoption. To consider this possibility, we asked the 54 survey respondents who were not using an alternative practice whether they agreed or disagreed with three true statements that represent a basic understanding of alternative N management systems. The responses reported in Table 7 suggest there was limited recognition of the technical aspects of the various alternatives. Only 39% of the respondents believed that split N would reduce total application requirements, only 35% believed that most of the N requirement of the corn crop could be met by a legume green manure, and only 31% believed the possible carryover of N from the legume.

Summary and Conclusions

When a mass balance framework is incorporated into N management decision analysis, results suggest that splitting N applications and using poultry litter as a source of N may increase net returns and reduce N residuals. Using a legume winter cover crop as a green manure also may reduce N residuals substantially. Such a system becomes more profitable as the cost

Table 7. Survey respondents who do not use alternative systems: percentage agreeing or disagreeing with true statements about N management systems (n=54).

Statement	Agree	Disagree	Don't Know
Splitting N reduces the total N required	39%	33%	28%
A legume can supply most of the N needed for the following crop	35%	37%	28%
A legume will provide some N to a wheat crop following the corn crop	31%	39%	30%

of inorganic N fertilizer rises from either market forces or a tax. Results of a survey of farm operators in the case study area suggest that both incentives and education about the economics and technical aspects of alternative systems may be needed to encourage a shift away from conventional practices.

This analysis has assumed climate and geological conditions typical of the mid-Atlantic coastal plain region, with model coefficients derived from the agronomy and soil science literature. Key relationships assumed in the study may vary in different regions. The mass balance approach does not predict the eventual fate of N not used by crops. However, the study shows the importance of considering the N cycle fully, including the carryover and mineralization of N, in analyses of N management and its impact on surface or groundwater.

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RESOURCES

A video on the sustainable farming practices of Dick and Sharon Thompson is available for $19.95 from The New Farm Library, The Rodale Institute, 222 Main St., Emmaus, PA 18098.

The Road from Rio: An Agenda for U.S. Follow-up to the Earth Summit is $10 from Environmental and Energy Study Institute, 122 C St., NW, #700, Washington, D.C. 20001-2109.

PASA Passages, the newsletter of the new Pennsylvania Association for Sustainable Agriculture, is available to PASA members; contact: PASA, PO Box 316, Millheim, PA 16854.

Conservation Policies for Sustainable Hillslope Farming is $30 from Soil and Water Conservation Society, 7515 N.E. Ankeny Road, Ankeny, IA 50021-9764; 1-800-THE-SOIL.

The Hedgerow Project: A Review of the Literature, about sustainable hedgerow planting in agriculture, is available from the Hedgerow Foundation, 5745 South Harper Avenue, Chicago, IL 60637; (312)493-8059.

Fields of Green is a four-part video series on sustainable agriculture produced by Organic Farm Services, Canada; for more information, contact Tomas Nimmo, producer, Box 116, Collingwood, Ontario, L9Y 3Z4, Canada; (705)444-0923.

Consumer's Organic Mail-Order Directory, a directory of the organic food industry, is available for $9.95 plus $2.50 shipping/handling from California Action Network, PO Box 464, Davis, CA 95617; 1-800-852-3832 or (916)756-8518.

Growing Season, a 25-minute documentary about an innovative organic gardening program at the San Francisco County Jail, is available free to grassroots organizations for use in educational and organizational work. Contact: Nicholas Wellington, 152 29th St., San Francisco, CA 94110; (415)641-7943.

Farm Profiles Invited

For its new department on alternative agriculture profiles, the *AJAA* welcomes short articles describing farmers who have adopted interesting alternative practices. The articles should include five elements: a brief description of the farm; the problems that made the farmer look for an alternative approach and the reasons why the alternative seemed plausible; a summary of the basic principles behind the alternative (possibly in a sidebar if it interrupts the flow of text); a discussion of how well the alternative has worked; and a discussion of the applicability of the alternative for other farms. The length should be 1500 to 2000 words.

Submissions must be accompanied by a release, signed by the farmer, giving permission for this material to be published in the *American Journal of Alternative Agriculture*. Vol. 3, No. 4, of the *AJAA* has a further description of the department (page 188); or query the editor for further information. Send submissions to the Editor, *AJAA*, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770.

Integrated resource management for sustained crop production in arid regions of India

J.P. Gupta and R.K. Aggarwal

Abstract. *In arid areas of western Rajasthan, major constraints responsible for low plant production include low and erratic rainfall, high evaporation, and low soil fertility, particularly with respect to organic carbon and nitrogen. These problems lead to acute shortages of grain, fodder and fuelwood. Sustainable crop and biomass production can be achieved through adoption of agroforestry, silvipastoral, and agrihorticultural systems. Integrated nutrient and moisture management practices can help in controlling pathogens and in improving the soil environment for higher sustained production.*

Key words: agricultural sustainability, agroforestry, agrihorticulture, silvipasture, farming systems

About 32 million ha of India, consisting of Rajasthan, Gujarat, Haryana, Punjab, Andhra Pradesh and Karnataka, suffer from aridity. The combination of limited, uncertain rainfall and high evaporative demand frequently causes crop failures in these areas. Furthermore, the need for grain, fodder and fuel has increased markedly because of the rapid increase in human population in arid Rajasthan from 9.8 million in 1971 to 13.4 million in 1981, and the increase in the number of animals from 10.3 million in 1951 to 23.3 million in 1983. Therefore, it is essential to manage available resources in a more judicious, balanced way for higher sustained production.

Alternatives to Sole Cropping Systems

Agroforestry

Because of a harsh climate and uncertain rainfall, arable cropping is extremely risky. Farmers in arid areas, aware of these constraints, traditionally use agroforestry. In particular, they intercrop agricultural crops such as pearl millet *(Pennisetum typhoides* [Burm.f.] Stapf & C.E. Hubb.), mung bean (*Vigna radiata* [L.] Wilczek), cluster bean (*Cyamopsis tetragonolobus* [L.] Taub) and sesame (*Sesamum indicum* L.) with *Prosopis cineraria*. They thereby obtain higher crop yields, possibly because of addition of nutrients through trees (Table 1). However, *P. cineraria* is slow growing. A fast growing variety has been developed at CAZRI that quickly meets the needs of farmers for fuelwood and fodder. Other leguminous trees, such as *Hardwickia binata*, *Acacia nilotica*, and *Colophospermum mopane*, if grown with crops, also meet part of the crops' nitrogen requirement, besides providing fuelwood and fodder.

Agrihorticulture

Budded ber (*Zizyphus mauritiana*) is an important fruit tree of arid regions. Intercropping mung bean with *Z. mauritiana* (400 trees per ha, 3 years old) can be more profitable than sole cropping, even under low rainfall conditions (Table 2). This is an improvement over the current practice of growing agricultural crops with "jar-beri" (*Z. rotundifolia*) because the yields of fruit and fodder are higher and the quality is better. During extended droughts, if annual crops fail, the fruit trees help stabilize the farmer's income.

Silvipastoral systems

Silvipastoral systems involve intercropping of grasses like *Lasiurus sindicus* and *Cenchrus ciliaris* with *Zizyphus nummularia* (another species of "jar-beri") or *Acacia tortilis*. These systems can be highly sustainable, even under the extremely low rainfall (100 to 200 mm) of Jaisalmer, Bikaner and Barmer (Gupta and Sharma, 1991).

Improved Management Methods

High-yielding crop varieties

Traditional varieties are drought resistant, but they do not use inputs efficiently, and respond poorly to improved management. Therefore, their yields are low.

High yielding varieties, on the other hand, use inputs efficiently and respond to improved management. Even with low use of inputs, these varieties could yield more than traditional varieties. Some improved varieties, such as pearl millet MH-179, cluster bean 'Maru guar', moth bean (*Phaseolus aconitifolius)* 'Maru moth', mung bean S-8, and cowpea FS-68, perform remarkably well in arid areas and resist pests and diseases.

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Table 1. Increase in soil nutrients (0 to 15 cm depth) with *Prosopis cineraria* trees (Aggarwal and Praveen Kumar, 1990).

Nutrients	With *P. cineraria*	Without *P. cineraria*
Total nutrients (%)		
Organic matter	0.57	0.37
N	0.04	0.02
S	0.03	0.02
P	0.04	0.03
Available nutrients (kg/ha)		
N	250	150
P	22.4	7.7
K	633	370

Table 2. Mung bean yield as affected by intercropping with ber trees (3 years old, 400 trees per ha).

Treatment	Rainfall (mm)	Ber yield (kg/ha)	Grain yield (kg/ha)	Economic return (Rs/ha)	Increased profit (Rs/ha)
Normal planting	210	-	620	4,800	-
Intercropped	210	800	160	7,680	2,880

Table 3. Effect of organic manure and N fertilizer on the grain yield of pearl millet for different amounts of rainfall (Aggarwal and Ventkateswarlu, 1989).

N fertilizer and manure treatment	Rainfall		
	Above normal (260 mm)	Normal (220-260 mm)	Below normal (200 mm)
	Grain yield (kg/ha)		
Control	1,340	750	250
10 kg N + 10 t farmyard manure per ha	2,020	1,500	680
20 kg N per ha	2,070	1,180	450

Table 4. Effect of phosphate fertilizer on soil improvement by grain legumes (Kathju et al., 1987).

Crop	P_2O_5 application (kg/ha)	Soil nutrients, 0 to 15 cm depth		
		Organic C (%)	Total N (kg/ha)	N fixed (kg/ha)
Mung	0	0.18	564	131.6
	40	0.21	690	273.0
Guar	0	0.18	558	75.6
	40	0.20	615	145.7

Limited use of fertilizers

In arid areas, fertilizer use is very low, perhaps because of uncertain rainfall. Applying N at a rate of 10 to 20 kg/ha is highly profitable. A blend of inorganic fertilizer N at 10 kg/ha and farmyard manure at 10 t/ha increased the production of pearl millet even when rainfall was below normal (Table 3), and also improved soil physical conditions and productivity (Gupta, 1989). Balanced, judicious use of fertilizers is important for increasing crop production even under low rainfall.

Grain legumes generally are grown without fertilizer in arid areas. However, modest application of P (P_2O_5 at 40 kg/ha) can increase the organic matter status, total N, and N fixed by legumes in soils that are medium to deficient in P (Table 4), thereby increasing grain production. When grown in rotation with cereals or millets, these legumes help supply fixed N, and thereby reduce the fertilizer requirement of the non-legume crop. This is a way to avoid excessive use of fertilizer with its adverse effects.

Reduced tillage for improving the soil environment and controlling weeds

The old Indian concept that more tillage means more grain is not tenable, particularly in arid areas with light sandy soils. Excessive tillage degrades the soil by destroying clods, increasing wind erosion, and forming crusts. It also consumes fuel and increases the cost of production. No-till, on the other hand, seriously impedes the establishment and growth of plants because of weed competition and poor soil physical conditions, including high soil strength and bulk density, and low water infiltration. Reduced tillage, however, has been found to be highly useful in improving the soil physically and increasing crop yields (Table 5) without harming the environment (Gupta, 1987).

Post-emergence cultivation is essential not only for controlling weeds but also for providing a favorable environment for root growth and for efficient use of water and nutrients (Gupta and Gupta, 1982). One cultivation to a depth of 5 cm, 20 days after seedling emergence, significantly reduced weed pressure and increased yield of pearl

Table 5. Effect of tillage on crop yield on a loamy sand in Jodhpur.

Treatment	Mean grain yield (kg/ha)		
	Pearl millet (1982-1985)	Cluster bean (1982-1984)	Mung bean (1985-1986)
No tillage	1,350	760	470
Reduced tillage	1,550	1,140	580

Table 6. Effect of post-emergence cultivation on the weed production and yield of pearl millet (1978).

Treatment	Weeds (kg/ha)	Grain yield (kg/ha)
No cultivation	1,720	50
One cultivation	60	1,140

Table 7. Effects of mulching on soil environment, fungal propagules, and growth of cluster bean.

Treatment	Soil bulk density (g/cm^3)	Moisture content (%)	Temperature (°C)	Fungal propagules (number/g)	Seedling mortality (%)	Plant height (cm)
No mulch	1.40	6.2	42.3	30.2	25	13.5
Mulch	1.37	7.6	37.6	8.5	18	35.0

Table 8. Effects of water harvesting on disease incidence, growth and yield of pearl millet.

Treatment	Available soil moisture (%)	Disease incidence (%, 40 days after sowing)	Infection index at drought stage (%)	Grain yield (g/plant)
Flat sowing	31.7	53.0	60.4	6.0
Sowing with water harvesting	47.0	31.2	41.0	7.4

millet (Table 6). This is a way to control weeds while avoiding the use of herbicides, which are expensive and not always available.

Soil and moisture management for disease control

Management to improve soil and moisture conditions is essential for increasing the health and vigor of seedlings so that they escape disease infestation. Studies at CAZRI in 1982-1983 showed that mulching between the rows improves the soil's moisture status by reducing evaporation and soil temperature (Table 7). The favorable conditions thus created reduced the number of propagules of the fungus *Macrophomina phaseolina*. Seedling mortality of cowpea was reduced, so that the establishment and stand were improved (Gupta and Gupta, 1986).

Water harvesting techniques help to provide additional water to the crop by increasing the moisture stored in the soil profile. The results of a 1988 CAZRI study (Table 8) illustrate the improvement in soil moisture from water harvesting, which reduced the incidence of downy mildew in pearl millet and increased grain yield (Gupta and Gupta, 1988). Such results clearly show the importance of proper soil and moisture management in reducing the incidence of disease.

Conclusions

With the increase in both human and animal populations in arid regions, the demand for grain, fodder and fuelwood is increasing. These demands can only be met by increasing production through integrated resource management and modern crop production techniques. Excessive use of fertilizers and pesticides is harmful, but limited, judicious, balanced use is necessary. Integrated management of soil, plant, and water resources, with minimum input of chemicals, can lead to higher, sustained production without adversely affecting the environment.

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Letters

To the Editor:

In her article "Sustainable agriculture: The wildlife connection" (*AJAA* 6(4):161-167) Ann Y. Robinson discusses integrating wildlife with farm practices. This is an interesting approach to the complicated question of where to foster wildlife. However, I question Ms. Robinson's seeming lack of attention to the crucial matter of competition between domesticated and wild animals. There is a limited amount of food in any farming situation, and it would seem that as much as possible, the farmer would want to put resources into the harvested crops, not into the mouths of wildlife.

Also, has Ms. Robinson considered integrating competing native species of an area into the agricultural system? Wildlife need not simply exist on a farm alongside the crops and livestock herds, but instead could be regarded as a herd to be utilized. For example, the farmer could allow deer to forage, but also could sell permits to have them hunted and sell their hides and meat.

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Author's Response:

Competition between domesticated and wild animals involves dynamics that depend very much on local circumstances and pests. Some species get out of control because of the ecological simplification of the countryside, one characteristic of which is reduction of predators. This lays the groundwork for species that once were insignificant as pests to flourish. An advantage to reviving biodiversity on farms at least theoretically, is that such systems will restore a greater environmental balance, eventually reducing threats from any one organism. Also, diversity spreads economic risk so that the consequences of pest outbreaks are lessened.

Another cause of pest problems is loss of habitat, which forces wildlife such as waterfowl to become more concentrated. Formerly the birds would have been dispersed, causing little harm. Now, in some cases, even though overall numbers are down, more birds must congregate in smaller areas, where they can become a serious problem.

Many states where wildlife-related crop losses are significant have programs to compensate farmers for lost profits. This is a positive way for the public to share with landowners the costs of maintaining wild populations of animals.

The idea of integrating "competing native species of an area into the agricultural system," as Ms. Siedlecki suggests, is controversial in wildlife management circles. Wildlife and fish currently represent significant economic value. For example, in 1985, hunters spent nearly $264 million pursuing their prey, supporting nearly $400 million in business activity. In the U.S., wild animals, which often range across ownership boundaries, are considered "public" property. The state holds the authority to sell hunting permits. Even so, many landowners find creative ways to obtain benefit from allowing outdoor enthusiasts to enjoy wildlife on their property. The degree to which this happens depends on state law and local custom, but more could probably be done to allow landowners to gain economically from wildlife.

However, outright marketing of wildlife has serious potential drawbacks. A good discussion of the problems can be found in an article by Dr. Valerius Geist in *Conservation Biology* (March 1988). Dr. Geist argues that markets for hunting privileges and for wildlife meat and parts eventually reduces the public stake in wildlife conservation, hands wildlife to the wealthy, and allows disastrous raids on select species for profit. Most damaging, he says, is the placing of a market value on dead specimens of vulnerable wildlife, inviting exploitation not seen since the Wild West days of unfettered market hunting.

It is important to remember that many landowners view wildlife more as complementary than competitive, and appreciate the aesthetic, recreational and even spiritual benefits wild creatures offer. But appreciated or not, perhaps the wild species that inhabit the land have an intrinsic claim to exist. If so, we have an obligation to make reasonable accommodation for them.

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Effect of row width on herbicide and cultivation requirements in row crops

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Abstract. *Crops grown in narrow rows (NR, 0.25 to 0.38 m) shade weed seedlings more than do those grown in traditional wide rows (WR, 0.76 m). NR crops may require less herbicide and interrow cultivation than WR crops for equally effective weed control. This hypothesis was tested by comparing weed control and crop yield in NR and WR crops when the following percentages of recommended application rates (RAR) of standard herbicides were applied: soybean, 0, 50 and 100%; sunflower, 0, 25, 50, and 100%; and corn, 0, 33, and 100% in three separate sets of experiments conducted over 2, 3, and 4 years, respectively. In all treatments with 100% RAR, excellent weed control prevented reductions in crop yield. When only 25 to 50% RAR was applied, weed control was consistently high in NR (82 to 99% control), but variable in WR (42 to 99% control). Weed control and crop yields typically were lowest in NR without herbicides. Interrow cultivation controlled 0 to 81% of weeds in WR crops. In reduced herbicide treatments (25 to 50% RAR), yields of NR soybean and sunflower typically were about equal to those in WR with 100% RAR, but NR corn yields were about 10% less. Considering the reduced herbicide use and lower weed control costs, planting corn, soybean, and sunflower in narrow rows may represent a practical form of low-input production of these important crops.*

Key words: Low-input agriculture, sustainable agriculture, weed control, row width, corn, maize, soybean, sunflower

Introduction

Low commodity prices and high production costs have decreased the profitability of modern row crop production. Also, environmental problems, such as water contamination and soil erosion, are associated with intensive use of herbicides and tillage in row crops. Together, these factors may limit the continuation of some production systems. For agriculture to be sustainable, inputs must be used judiciously to maintain high yields while minimizing costs and potential environmental damage.

Weeds are important economic and ecological variables in production of corn (*Zea mays* L.), soybean (*Glycine max* [L.] Merr.), and sunflower (*Helianthus annuus* L.). Weeds are controlled in these crops primarily by herbicides, tillage, and crop competition. Herbicides used with corn, such as atrazine, or with all three crops, such as alachlor, are highly effective for weed control, but suffer two important disadvantages. First, they are the most common pesticides found contaminating groundwater and surface water (National Research Council, 1986). Second, they may represent a major production cost for producers (Lybecker et al., 1988), even if their use is economical.

Interrow cultivation is another effective form of weed control (Cates and Cox, 1912), especially when used with herbicides. However, it is an additional production cost for producers (Lybecker et al., 1988) and requires from 5 to 10 l/ha of fossil fuel. Cultivation normally is associated with wide rows (WR). Wide rows promote soil erosion in the Midwest (Mannering and Johnson, 1969), because the soil is exposed longer in early summer when rainfall and raindrop impact are greatest.

The competitive effects of corn, soybean, and sunflower plants are free and environmentally harmless, but are insufficient as the sole weed control in conventional WR plantings. Lack of appreciable competitive ability to aid in weed control arises because canopies of these crops develop too slowly to compete effectively with weeds (e.g., Robinson et al., 1967).

The competitive advantage of crops over weeds can be increased by manipulating crops genetically (Callaway, 1992) or culturally (Auld et al., 1983). Cultural manipulation of crops for increased competitive ability may include altering sowing density and geometry. For example, soybean canopy closure was hastened by sowing in narrow rows and high densities. This resulted in more light interception, less weed competition, and lower herbicide requirements than in conventional soybean production (Burnside and Colwell, 1964; Peters et al., 1965). These findings for soybean have never been extended to corn or sunflowers, perhaps because high densities of tall-stature crops often result in severe lodging and low yields (Nelson and Ohlrogge, 1957; Pendleton and Seif, 1962; Carter, 1985). However, some modern corn and sunflower varieties have been

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bred specifically to resist lodging at high densities (Zuber and Kang, 1978; Majid and Schneiter, 1987; 1988). These varieties provide an opportunity to study the effect of altered planting density or geometry on crop canopy development and weed control. Consequently, our objective was to examine the potential for achieving effective weed control using reduced herbicide application rates without interrow cultivation with modern corn, sunflower, and soybean varieties grown in narrow rows.

Materials and Methods

All experiments were conducted at the University of Minnesota West Central Experiment Station, Morris (45°35′N, 95°53′W). In each experiment, the preceding crop was corn. The plots were moldboard plowed in autumn, and disked and harrowed in May; all crops were planted in mid to late May at 0.05 m depth. In all experiments, interrow cultivation, when used, occurred about 4 weeks after planting. Major weeds competing with crops were similar in all experiments. In decreasing order of importance, these were robust green foxtail (*Setaria viridis* var. *robusta-purpurea* Schreiber), yellow foxtail (*Setaria glauca* [L.] Beauv.), redroot pigweed (*Amaranthus retroflexus* L.), and common lambsquarters (*Chenopodium album* L.).

Corn experiments

The experimental site was on an Aastad clay loam soil (Pachic Udic Haploboroll; fine, mixed, mesic) in 1986, 1988, and 1989. In 1987 the site was on a La Prairie loam soil (Cumulic Udic Haploboroll; fine, loamy, mixed). Soil was fertilized with 200 kg N/ha in 1986, 1988, and 1989, and with 150 kg N/ha in 1987. Soil was irrigated regularly to eliminate water stress as a limiting production factor in 1988 and 1989.

Each year, two hybrids were planted at two densities. The hybrids compared were P.A.G. SX123 (a dwarf hybrid with a 75-day maturity rating) and Pioneer 3790 (normal height, 95-day) in 1986, 1988, and 1989. In 1987, SX123 was compared with Land O'Lakes 181 (normal height, 75-day). Plots were sown and later thinned to achieve corn densities of 125,000 and 188,000 plants/ha for the dwarf hybrid (DC), 50,000 and 75,000 plants/ha for the normal-stature hybrid (TC) in 1986 and 1987, and 62,500 and 87,500 plants/ha for TC in 1988 and 1989. These ranges of corn populations were chosen to include densities recommended by the hybrids' developers: conventional population density (62,500 plants/ha) of DC would have low yield potential, and a high population density (>87,500 plants/ha) would be expected to lodge severely.

In row crops, a high within-row population increases intracrop competition more than crop/weed competition (Forcella and Burnside, in press). Therefore, to reduce intracrop competition, DC always was planted in narrow (0.38 m) rows. In contrast, the relatively low TC populations were planted in both narrow and (conventional) wide (0.76 m) rows.

Herbicide treatments consisted of preemergence application of 0, 33, or 100% of recommended application rate (RAR or labeled rate) of alachlor and cyanazine. The 100% RAR were 2.2 kg a.i./ha for alachlor, and 3.3 kg a.i./ha (2.2 kg/ha in 1987) for cyanazine (Becker et al. 1988). Herbicides were incorporated mechanically to 0.05 m in the dry spring of 1987, and incorporated with 0.02 m irrigation water in 1988 and 1989. Herbicides were applied with a CO_2-pressurized backpack sprayer at 185 l/ha, under 276 kPa, through a 3.1 m-wide boom.

Field plot design was a split-block with 4 replications (blocks). Each block contained 3 main plots: (1) narrow-row DC, (2) narrow-row TC, and (3) wide-row TC. Main plots were divided into three subplots (herbicide rates). Each subplot consisted of two subsubplots (corn densities), which henceforth will be referred to simply as "plots". Plot dimensions were 6.1×15.2 m. To isolate the effect of cultivation from that of herbicide application in wide row plots in 1988 and 1989, an additional treatment was included in the wide-row TC main plot. This plot received neither herbicide nor interrow cultivation. All other wide-row plots in all years were cultivated once in late June when corn was about 0.30 m tall.

Aboveground weed dry matter (DM) was determined in late July by clipping, oven-drying, and weighing all weeds in two 1.52 m^2 quadrats in each plot. We calculated weed control by subtracting weed DM in each plot from the value for the treatment within each block with the greatest weed DM (DM_{max}), dividing the difference by DM_{max}, and multiplying the quotient by 100. This procedure was necessary because any of the three or four 0% RAR treatments in each of these experiments could be considered "weedy checks".

Light interception by crop canopies in the 100% RAR treatments was measured in mid-June, during rapid crop canopy development, using a commercial, 0.8-m long, visible light sensor. Instantaneous measurements were recorded above and below the canopy at four points in each plot.

Corn grain was harvested mechanically in autumn in 23.1 m^2 units of each plot. Percentage grain moisture was measured, and grain yields were adjusted to 15.5% moisture.

We performed analysis of variance (ANOVA) on weed DM and corn yield data. Preliminary analyses revealed no significant effect from corn population, so the data were averaged over populations. Least significant difference (LSD) was calculated at the 0.05 probability level. Additionally, we used Student's t to compare differences ($p < 0.05$) between specific pairs of values.

Sunflower experiments

The experimental site was on an Aastad clay loam soil in 1986, and an adjacent Nutley clay (Udertic Haploboroll; fine, montmorillonitic) in 1987 and 1988. Soil was fertilized with 100 kg N/ha in each year.

Normal-height (TS) and dwarf (DS) hybrids were compared: SIGCO 475 (TS with a 95-day maturity) and SIGCO 461D (DS, 80-day) in 1986; SIGCO 475 and SIGCO 5733D (DS, 100-day) in 1987; and SIGCO 475 and SIGCO 471D (DS, 95-day) in 1988. We did not know the DS maturities before the experiments, so that we changed DS hybrids yearly to find one with a maturity equivalent to that of

SIGCO 475. Seeding densities were adjusted to obtain 125,000 DS plants/ha in 0.25 m-wide rows, and 62,500 TS plants/ha in 0.76 m-wide rows.

Weeds were controlled by cultivation, herbicides, or both. Herbicides were applied at 4 rates each year: 0, 25, 50, and 100% RAR (Becker et al., 1988). Herbicide treatments at 100% RAR were alachlor, applied preemergence at 3.3 kg a.i./ha in 1986; and trifluralin preplant incorporated at 1.1 kg a.i./ha. Application equipment was as with corn. Interrows of DS plots never were cultivated. No TS plots were cultivated in 1986, whereas all TS plots were cultivated once in 1987. In 1988 the number of TS plots was doubled; half were cultivated once and half were not cultivated. Sunflowers were about 0.30 m tall at time of cultivation.

Plot layout was in a split-block design with four replications (three in 1986). Each block contained main plots composed of either DS or TS (and TS-cultivated in 1988). Each main plot was divided into four subplots, which represented herbicide treatments. Subplot size was 3.1 × 9.1 m.

Weed DM was sampled at harvest in autumn. Weed DM was determined by clipping, oven-drying, and weighing weed topgrowth from two 0.76 m^2 quadrats in each subplot. We calculated percentage weed control as in the corn experiments.

In September, two rows of sunflower heads in each TS subplot, and 4 rows in each DS subplot were hand-harvested, air-dried, weighed, and threshed. Seeds were cleaned and weighed, and moisture content was measured. Yields were adjusted to 15.5% seed moisture. Because of bird and insect damage to sunflower heads, yields were expressed as DM for 1987 and 1988. DM was determined by harvesting, air-drying, and weighing total topgrowth of harvested plants in October 1987 (after leaf drop) and September 1988 (before leaf drop).

Between 33 and 55 days after planting (DAP), midday light interception by sunflower canopies was estimated in all 100% RAR plots. Interception was measured as in the corn experiments.

We performed ANOVA on all weed control and crop yield data. LSD was calculated based on the 0.05 probability level. For light interception data, we used t-tests ($p < 0.05$).

Soybean experiments

The experimental site was on an Aastad clay loam soil in both 1987 and 1988. 'Evans' soybean was planted at 500,000 seeds/ha in both 0.38 m and 0.76 m-wide rows.

Grassy weeds were controlled by three rates of trifluralin (rototilled for incorporation), equivalent to 0, 50, and 100% RAR (Becker et al., 1988), with the highest rate equalling 1.1 kg a.i./ha. All wide-row treatments were cultivated once in June; narrow-row treatments received no supplemental weed control. Acifluorfen was applied postemergence to all plots to eliminate broadleaf weeds that occurred in some plots. Consequently, green and yellow foxtails were the only weeds that interfered with the crops in this experiment. Herbicides were applied as described previously.

Plots were arranged in a split-plot design with four replications (blocks). Plots represented herbicide application rates and subplots represented row widths. Subplot sizes were 6.1 × 15.2 m.

Weed control (on July 1st), canopy light interception, and crop yield were evaluated as in the 1987 and 1988 corn experiments, except that yield was calculated based on 13% seed moisture. Preliminary ANOVA of weed and crop data revealed no significant effect from year of experimentation. Therefore, all yearly soybean data were averaged and reanalyzed with ANOVA. Light interception data were compared using t-tests ($p < 0.05$).

Results and Discussion

Weed control

Corn. Weed DM was consistently greatest in 0% RAR treatments. Yearly maximum DM varied among treatments: 1.8 (narrow-row TC), 3.6 (narrow-row DC), and 4.8 and 4.6 Mg/ha (wide-row TC without cultivation) from 1986 to 1989, respectively. Weed management methods in other treatments reduced these maximum DM accumulations (Table 1). The greatest reduction occurred with full RAR of herbicides, where weed DM consistently was reduced by 94% regardless of the hybrid, row width, and cultivation variables. These variables, however, did influence weed control differentially at reduced herbicide rates.

At one-third RAR, weed control in cultivated wide-row TC ranged from 62 to 98% (Table 1). Narrow-row TC attained weed control values ranging from 76 to 91%, and that for DC was 86 to 94%. None of these values differed significantly from maximum weed control values obtained with full RAR, except for wide-row TC in 1986.

When both herbicides and cultivation were omitted, weeds in wide-row corn were not controlled, with DM reduced by only 0 to 3% compared to the weediest plots (data not shown). However, when interrows were cultivated once, weed control increased to between 26 and 81% (Table 1). In narrow-row treatments, which lacked cultivation, weed control ranged from 40 to 52% in TC and 0 to 66% in DC. Generally, narrow rows achieved weed control equivalent to a single cultivation in wide rows, although such levels were inadequate to prevent a reduction in crop yield.

In summary, narrow-row corn competed well enough with weeds to effectively eliminate the need for cultivation and two-thirds of the normally applied herbicide rate.

Sunflower. Weed DM was consistently greatest in 0% RAR treatments. Yearly maximum DM was 2.6 (1986, non-cultivated TS); 4.6 (1987, DS); and 0.7 Mg/ha (1988, non-cultivated TS). Weed management methods in other treatments reduced these maximum DM accumulations (Table 2). For example, with full RAR weed DM consistently was reduced by >85% and never differed significantly among row widths.

With reduced herbicide rates (25 to 50% RAR) weed control in cultivated TS was consistently high (90 to 99%), as was that of DS (86 to 99%), whereas non-cultivated TS was variable (7 to 99%). Without herbicides, weed DM in wide-row TS (plus cultivation) was reduced 59 to 86%, but

Table 1. Weed control (%) in cultivated wide-row corn and in narrow-row tall and dwarf corn with three fractions of the recommended application rate (RAR) of tank-mixed alachlor and cyanazine.

	no herbicide			33% of RAR			100% of RAR		
Year	wrt[1]	nrt	nrd	wrt	nrt	nrd	wrt	nrt	nrd
1986	26a[2]	52ab	54b	62bc	76bcd	86cd	100d	100d	100d
1987	57a	---[3]	0a	92c	---	88c	96c	---	94c
1988[4]	50a	46a	66ab	98c	91bc	94bc	97bc	100c	100c
1989[4]	81c	40a	62b	95de	84cd	94de	98e	95de	96de

[1] Row width and variety abbreviations correspond to: wrt = wide-row tall corn, nrt = narrow-row tall corn, and nrd = narrow-row dwarf corn.
[2] Values within rows with no letters in common differ significantly according to ANOVA and LSD ($p < 0.05$).
[3] The nrt treatment was not planted in 1987.
[4] Uncultivated wide-row corn receiving no herbicide had greatest average weed DM of all treatments, corresponding to weed control values of 3% in 1988 and 0% in 1989.

Table 2. Weed control (%) in narrow-row, uncultivated wide-row, and cultivated wide-row sunflower with four fractions of the recommended application rate (RAR) of sunflower herbicides.

	nrd-u[1]				wrt-u				wrt-c			
	(% RAR)											
Year	0	25	50	100	0	25	50	100	0	25	50	100
1986	0a[2]	89bc	86bc	97c	0a	7a	54b	100c	---	---	---	---
1987	0a	88bc	90bc	98c	---	---	---	---	59b	90bc	97c	99c
1988	67b	98d	99d	99d	0a	76bc	99d	99d	86cd	97d	99d	100d

[1] Row width and variety abbreviations correspond to: nrd = narrow-row dwarf, wrt-u = wide-row tall - uncultivated, and wrt-c = wide-row tall - cultivated.
[2] Values within rows with no letters in common differ significantly according to ANOVA and LSD ($p < 0.05$).

control was 0% in non-cultivated wide-row TS, and 0 to 67% in narrow-row DS.

In summary, these findings again indicated that narrow rows for weed control could replace a single cultivation and three-fourths RAR of herbicide.

Soybean. Weed DM was consistently greatest in narrow-row soybean without herbicides in both 1987 and 1988, averaging 0.56 Mg/ha in early July. Weed DM in narrow-row soybean was reduced by 94% in both the one-half and full RAR, and by 44, 94, and 100%, respectively, in the zero, one-half, and full RAR treatments in cultivated wide-row soybean (LSD = 20).

In summary, these results agree with those of Burnside and Colwell (1964) and Peters et al. (1965). They are further evidence that for weed control in soybean, narrow rows are equivalent to a single interrow-cultivation and one-half RAR of herbicide.

Yields

Corn. Yields typically were highest when corn was planted in wide rows and weeds were controlled by both cultivation and the highest herbicide rate (Table 3). Yields of DC were much less than these maximum yields, but narrow-row TC approached maximum yields, especially in the full and one-third RAR treatments. Relative to yields obtained by cultivated wide-row TC with full RAR (the conventional treatment), percentage yields of DC and narrow-row TC, averaged over years were as follows: full RAR, 71% and 98% (Student's $t = 3.6$ and 0.9); one-third RAR, 68% and 90% ($t = 4.7$ and 3.4); and no herbicide, 52% and 79% ($t = 6.4$ and 2.5). The data indicate that although yield was reduced in narrow-row TC when only one-third RAR was applied, the reduction was small enough (10%) to consider this low-input treatment as potentially competitive.

In Minnesota, annual variation in yield largely can be attributed to the crop's soil water supply (Holt and Timmons, 1968). During the 1986 growing season, rainfall was 126% of average (Table 4), and yields were correspondingly high. In 1987, growing season rainfall was only 50% of average, and yields were very low (Table 3). Irrigation in 1988 and 1989 insured high soil water contents, and high yields resulted. The 1987 drought increased relative

Table 3. Yield (Mg/ha) of cultivated wide-row corn and of narrow-row tall and dwarf corn with three fractions of the recommended application rate (RAR) of tank-mixed alachlor and cyanazine.

	no herbicide			33% of RAR			100% of RAR		
Year	wrt[1]	nrt	nrd	wrt	nrt	nrd	wrt	nrt	nrd
1986	9.6cd	8.8bc	7.3a	9.2cd	8.9c	8.0ab	9.9d	9.8d	7.6a
1987	2.7b[2]	---[3]	1.6a	3.0bc	---	2.7b	3.4c	---	3.1bc
1988[4]	7.6c	5.6bc	3.6a	8.7e	7.6d	5.0b	8.9e	8.3de	5.4bc
1989[4]	8.2de	7.5cd	3.9a	8.6e	8.3de	4.9b	8.7e	8.8e	4.8ab

[1] Row width and variety abbreviations correspond to: wrt = cultivated wide-row tall corn, nrt = narrow-row tall corn, and nrd = narrow-row dwarf corn.
[2] Values within rows lacking a common letter differ significantly according to ANOVA and LSD ($p < 0.05$).
[3] The nrt treatment was not planted in 1987.
[4] Uncultivated wide-row corn receiving no herbicide yielded 6.0 Mg/ha in 1988 and 7.3 Mg/ha in 1989.

Table 4. Monthly precipitation and mean soil temperature (0.05 m) during the growing seasons of 1986 to 1989, and the historical mean, at the West Central Experiment Station, Morris, Minnesota.

Year	April	May	June	July	August	Total
			Precipitation (mm)			
1986	155	98	107	164	140	664
1987	10	74	47	46	37	214
1988	14	43	12	46	118	233
1989	61	49	117	109	77	413
Historical mean	65	79	98	87	76	405
			Mean soil temperature (°C)			
1986	7.4	14.5	19.8	21.9	18.0	na
1987	6.4	17.9	23.3	23.7	21.7	na
1988	10.6	16.1	20.0	22.2	18.6	na
1989	5.6	13.7	18.1	22.8	20.1	na
Historical mean	5.9	13.4	18.8	21.5	20.4	na

weed competition. Overall, relative yield loss due to weed competition in 1987 was 14.3% greater (S.E. = 2.6, t = 5.47, $p < 0.01$) than in the wet or irrigated years. Furthermore, average relative yield losses in 1987, compared to the wet years, were greater in both the 0% RAR (18%) and 33% RAR (11%) treatments, and in both the TC (11%) and DC (18%) treatments.

Sunflower. In all years, yields were highest when sunflower was planted in wide rows and weeds were controlled by the highest herbicide rate (Table 5). In 1986, when TS had a longer maturity than DS, TS yields were significantly higher than those of DS within each RAR treatment. Interestingly, DS appeared to reach its highest yield at 25% RAR, whereas TS yields tended to increase with increasing application rate. In 1987 and 1988, when hybrid maturities were closer, DS and TS yields were equivalent within RAR treatments. In 1987, both DS and TS appeared to reach highest yield at 25% RAR. Although weeds associated with DS and TS were subjected to the same herbicide rates within this RAR treatment, TS had the additional benefit of interrow cultivation in 1987. In 1988, RAR treatments did not significantly affect sunflower yields, regardless of variety, row width, or cultivation. This may have resulted because of extreme drought conditions in 1988 (Table 4) and lack of substantial weed growth (see discussion of sunflower in the earlier section on weed control).

Table 5. Yield (Mg/ha) of narrow-row, uncultivated wide-row, and cultivated wide-row sunflower with four fractions of the recommended application rate (RAR) of sunflower herbicides.

	nrd-u[1]				wrt-u				wrt-c			
	(% RAR)											
Year[2]	0	25	50	100	0	25	50	100	0	25	50	100
1986	0.6a[3]	1.6b	1.6b	1.7b	1.8b	2.3d	2.4d	2.5d	---	---	---	---
1987	2.6a	3.6c	3.7c	3.3bc	---	---	---	---	3.0ab	3.8c	3.7c	3.7c
1988	6.9a	6.3a	7.1a	7.3a	6.6a	6.3a	7.6a	7.6a	6.6a	6.4a	6.9a	7.7a

[1] Row width and variety abbreviations correspond to: nrd = narrow-row dwarf, wrt-u = wide-row tall - uncultivated, and wrt-c = wide-row tall - cultivated.
[2] Yields in 1986 represent that of seeds, whereas those for 1987 represent DM of leafless stems plus heads, and those for 1988 represent DM of stems plus leaves plus heads.
[3] Values within rows with no letters in common differ significantly according to ANOVA and LSD ($p < 0.05$).

Overall, these results indicate that narrow-row sunflower can attain its maximum yield potential with only one-quarter RAR. Dwarf hybrids of similar maturity produce yields in narrow rows equal to those of cultivated wide-row TS with full RAR.

Soybean. Yields of soybean in 0, 50, and 100% RAR treatments, averaged over years, respectively were as follows: 2.0, 2.8, and 2.7 Mg/ha in narrow-rows, and 2.2, 2.5, and 2.8 Mg/ha in cultivated wide-rows (LSD = 0.3 Mg/ha). Yields were not different within any RAR treatment, despite the added benefit of interrow cultivation in wide-row soybean treatments. Furthermore, yield of narrow-row soybean with one-half RAR was not different from that of cultivated wide-row soybean with full RAR.

These results are similar to those of Burnside and Colwell (1964) and Peters et al. (1965). They are further evidence that for soybean yield, narrow rows are equivalent to a single interrow-cultivation and one-half RAR of herbicide.

Canopy light interception

In mid to late June, approximately one month after planting, light interception values in corn for wide-row TC, narrow-row TC, and narrow-row DC canopies were as follows: 30, 35, and 40% (1986); 29, n/a, and 35% (1987); 30, 34, and 53% (1988); and 41, 51, and 73% (1989). All values for narrow rows were significantly greater than the corresponding values for wide rows.

In sunflower, canopy light interception values were calculated 4 to 8 weeks after planting. For TS and DS these values were as follows: 56 and 82% (1986), 18 and 27% (1987), and 85 and 93% (1988). All values for narrow rows were significantly greater than the corresponding values for wide rows. For soybean, canopy light interception in late June averaged 14% in wide rows and 31% in narrow rows, with the difference being significant.

Narrow-row crop canopies consistently intercepted more sunlight than wide-row canopies when measurements were taken early in the growing season. The result was greater shading of weed seedlings under narrow-row canopies. This may account for the greater ability of narrow-row crops to decrease weed interference compared to conventional wide-row crops, despite highly reduced herbicide application rates and absence of interrow cultivation.

Cost comparisons

Crop yields from all DC and 0% RAR treatments were too low for any of these treatments to be economically competitive. Therefore, these treatments are not considered further. Weed control and yields of cultivated wide-row crops with reduced herbicide rates often were high, but they also were variable. Consequently, the most interesting comparisons were conventional treatments (cultivated wide-row crop with full RAR) and low-input treatments (uncultivated, narrow-row, with reduced RAR) for the three crops.

In the northwestern Corn Belt, crop yields average about 6, 1.5, and 2 Mg/ha for corn, sunflower, and soybean, respectively (U.S. Dept. of Agriculture, 1982; Hardman, 1987; Schmidt, 1987). They are worth approximately $118, $331, and $220 per Mg, respectively. In the present studies, no yield penalties were apparent for narrow-row sunflower and soybean production with reduced RAR. However, narrow-row TC (with one-third RAR) decreased yield about 10%. Although this represents a $71/ha loss in income, some of this loss can be compensated for by lower production costs.

The most obvious cost savings for narrow-row crops come from omitting interrow cultivation and reduced herbicide application rates. Cultivation costs vary greatly (Lybecker et al., 1988), but $10/ha is within the range determined by agricultural economists. Retail herbicide prices fluctuate only moderately compared to crop commodity prices. For corn production, full RAR of alachlor and cyanazine might cost $58/ha (Becker et al., 1988), and the reduced rate (33% RAR) for narrow-row corn would cost $19/ha. Therefore, narrow-row corn production results in a total saving of about $49/ha. Deducting this from the narrow-row corn yield penalty of $71/ha results in a net penalty of $22/ha.

In sunflower and soybean production, the full RAR of trifluralin costs $20/ha (Becker et al., 1988). The half-rate RAR possible in narrow-row production of these crops represents a $10/ha saving. With the

absence of interrow cultivation, narrow-row sunflower and soybean production could increase net profits by $20/ha.

The long-term environmental benefits of wide-row and narrow-row production systems cannot presently be calculated. Nevertheless, these benefits for agriculture, whether in money, environmental safety, or simply assuaging public pessimism about herbicides (Forcella, 1988), also should be included in comparisons of conventional farming practices with low-input agriculture.

The high cost of inputs for conventional weed control, and its potential for soil erosion and off-site contamination by herbicides, are strong reasons for developing cultural systems that depend less on herbicides and cultivation. Narrow-row crops, particularly if they are rotated yearly with one another, may represent such a system.

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"Green" Clothing Increases Demand for Organic Cotton

Recognizing the consumer demand for environmentally responsible products, a major clothing manufacturer has launched a line of clothing made from organically grown cotton. Vanity Fair Corporation, whose brands include Lee, Wrangler, Health-Tex, and Jantzen, recently bought Green Cotton Environment, a small organic cotton clothing company, and named its products "O Wear," according to *In Business* magazine.

The company works with organic cotton growers in California, Texas, Arizona, Arkansas, Missouri, and Tennessee, and this year will buy more than three million pounds of organic cotton for $1 to $1.50 per pound—nearly double the market price for cotton grown with chemical fertilizers and pesticides. Approximately 75 percent of the farmers O Wear deals with are relatively new to organic farming, most of them converting 10 to 20 percent of their acreage to organic cotton. The merger of Green Cotton Environment and the clothing conglomerate, according to *In Business*, "showed recognition of a promising market opportunity as well as the realization that environmentally-based production practices are achievable."

Letters To The Editor Invited

The *AJAA* welcomes letters, short or long, commenting on articles in this journal or sharing ideas likely to be of interest to other *AJAA* readers. Since our space is limited, we do reserve the right not to publish all letters or, at times, to publish only excerpts from them. To take part in this exchange of ideas, write to: Editor, *AJAA*, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770.

INSTITUTE NEWS

Alternative Ag Policy Choices to be Explored at IAA Symposium

Alternative Agriculture Policy: A New Time to Choose is the title of the IAA's 10th annual symposium scheduled for March 1, 1993, in Washington, D.C. The purpose of the one-day forum, to be held in the National Rural Electric Cooperative Association building, is to better explore tomorrow's policy opportunities and means of encouraging a sustainable agriculture by learning from the past.

To set the stage, Lynn Daft, vice president of the consulting firm Abel, Daft & Earley, and Richard R. Harwood, sustainable agriculture leader at Michigan State University, will "revisit"—and relate to current interest in agriculture's sustainability—two landmark studies requested by U.S. Agriculture Secretary Bob Bergland during the late 1970s and published in the waning days of the Carter Administration. Daft is to revisit "A Time to Choose," a major report on the changing structure of American agriculture and its trouble spots. Harwood will examine another highly significant study entitled, "Report and Recommendations on Organic Farming."

Kathleen Merrigan, a principal member of the staff of the Senate Committee on Agriculture, Forestry, and Nutrition in recent years, will further relate the past to the future by drawing on the 1990 Farm Bill experience to identify sustainable agriculture policy options and strategies for the 1995 Farm Bill. The program will culminate with a roundtable discussion on specific interests and plans with leaders of the new Administration, the farming community, food and agricultural organizations, environmental groups, science and education leaders, and other interested persons. Summing up will be Dr. John Gordon, national leader in forestry and a new IAA Board member. For more information, contact the IAA at (301)441-8777.

IAA Survey Responses Reflect Diverse Membership

The responses of the IAA members who answered a survey mailed last fall reflect a diverse membership of people involved in sustainable agriculture. Of respondents, 12% live in the Washington, D.C., area; 13% in the Northeast; 12% in the South; 5% in the North; 31% in the Midwest; and 20% in the West.

Of those responding, 43% work at a university; 24% are self-employed; 15% work for non-profit organizations; 10% work for the federal government; 4% work for a state government; and 2% work at a trade association.

Respondents listed 285 other agricultural organizations they belong to. Some 66% found *Alternative Agriculture News* to be useful or highly useful, and 61% found the *American Journal of Alternative Agriculture* to be very useful or highly useful.

Keeney Is New President of American Society of Agronomy

Dr. Dennis Keeney, director of the Leopold Center for Sustainable Agriculture in Ames, Iowa, was recently installed as president of the 12,500-member American Society of Agronomy.

Dr. Keeney, a member of the IAA President's Council, is professor of agronomy at Iowa State University and has headed the Leopold Center since 1988. He also directs the Iowa State Water Resources Institute. His research specialties include the chemistry of soils, the cycling and efficient use of nitrogen, land application of wastes, and soil as a source of nitrous oxide.

Gordon Receives Conservationist of the Year Award

Dr. John Gordon, Dean of the School of Forestry and Environmental Studies at Yale University, recently received the Conservationist of the Year Award from the Pacific Rivers Council in Eugene, Oregon.

Dr. Gordon, IAA Board member-elect, received the award as a member of the Scientific Panel on Late-Successional Forest Ecosystems, which was commissioned by two committees of the House of Representatives to make a scientific analysis of management options for west side old growth forests. The Panel incorporated salmon and watershed management options into the analysis of management alternatives.

"For the first time, science provided a national framework for the management of Northwest forests along with associated risk assessments for each management option," said Bob Doppelt, Executive Director of the Pacific Rivers Council, who expressed the organization's "deep admiration for the Panel's work and its inestimable value to conservation work in the Northwest."

A compendium of crop varietal tolerance to weeds

M. Brett Callaway

Abstract. *Genetic improvements in crop tolerance to diseases, insects, and other stresses have reduced or eliminated applications of pesticides and other inputs for many crops. However, little work has been done to examine the potential for increasing levels of tolerance to weeds, even though herbicides account for 69% of the pesticides used in the United States each year. This paper documents that for all 21 crops examined, varieties differ in their tolerance of non-parasitic weeds. Characteristics influencing varietal tolerance to weeds are summarized.*

Key words: competition, genotypes, cultivars, varieties

Introduction

Plant breeders have conducted a great deal of work on increasing crops' tolerance to many pests and physiological stresses. However, relatively little has been done on increasing tolerance to weeds, even though herbicides account for 69% of the pesticides used in the United States each year (Pimentel et al., 1991). Reducing the number of weedings, and thereby the time devoted to a particular crop, would be extremely beneficial where herbicides are either unavailable or prohibitively expensive.

Differences in neighboring plants have been shown to produce a "fine-scale biotic differentiation" under natural conditions (Turkington and Harper, 1979). Clones of white clover (*Trifolium repens*) that had grown for many years in association with one of four grass species were collected and identified according to the grass with which they had been associated. Each clover clone was transplanted into a monoculture sward of each grass species, so that all clone-grass combinations were represented. On average, each clover clone performed best when grown in association with the grass species with which it originated.

In agricultural systems, genotypic variation for growth and for yield of one crop in the presence of another has been observed for many years. Only recently have attempts been made by plant breeders to apply this variation to cropping systems. However, most of this work has concentrated on multiple cropping systems rather than crop-weed systems.

How competitive ability and tolerance to weeds are defined is very important for the success of breeding programs. Clear definitions let the breeder focus selection efforts and evaluate progress accurately. Several measures of competitive ability have been used in the literature (Table 1), usually with no justification for their choice. Frequently, the way in which competitive ability is defined is never described. Goldberg and Landa (1991) identified two distinct ways of comparing competitive abilities: competitive effect (CE), or ability to suppress other individuals; and competitive response (CR), or ability to avoid being suppressed. This distinction has not often been made in studies of crop tolerance to weeds, thereby confusing the discussion. Both CE and CR may be important components of tolerance, although for most crops CR is of greater interest. Since varietal tolerance to weeds is simply an optional tool for improving the efficiency and sustainability of crop production systems, yield *per se* also is an important measure of tolerance. Therefore, "tolerance," as used in this review, includes competitive ability (CE and CR) and high yield under weedy conditions. The present review specifies how tolerance was assessed (Table 2).

Time-frame and objectives determine the relevant measure of tolerance. For near-release breeding lines or commercially available varieties, yield is of primary interest. The highest yielding varieties in weedy conditions should be selected for planting under similar conditions whatever their CR (or CE). However, when selections are made early in the development of varieties, CR may be more important, because characteristics conferring high CR may be incorporated into elite populations from which high-yielding, high-CR lines may be extracted.

Several characteristics influencing varietal tolerance to weeds are discussed in the following paragraphs and summarized in Table 3. Many mechanisms contribute to varietal tolerance to weeds. Tolerant varieties may be more efficient physiologically, resulting in higher yields under weed-free conditions and lower yield reductions under weedy conditions. (Wallace [1985] and Scully and Wallace [1990] discuss physiological efficiency of yield under weed-free conditions.) Maturity may improve tolerance by avoidance (for example, early maturing varieties avoid compe-

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Table 1. Frequently used measures of competitive ability.

Measures	Selected References
Proportional crop yield reduction	Burnside and Wicks, 1972; McWhorter and Barrentine, 1975; McWhorter and Hartwig, 1972; Moody, 1978; Rose et al., 1984; Staniforth, 1961
Amount of crop yield reduction	Challaiah et al., 1983; Flood and Halloran, 1984; Guneyli et al., 1969; Smith, 1974; Wilson et al., 1980
Amount of crop biomass reduction	Guneyli et al., 1969
Weed biomass reduction	Burnside, 1972; Challaiah et al., 1986; Charles, 1972; Guneyli et al., 1969; Moody, 1978; Soto and Gamboa, 1984; Wicks et al., 1986; Wilson et al., 1980; Yip et al., 1974
Crop yield reduction per unit weight of weed	Staniforth, 1961
Reduction of weed numbers	Wilson et al., 1980
Weed cover rating	Selleck and Dallyn, 1978; Wicks et al., 1986

Table 2. Tolerance assessment using competitive effect (CE), or ability to suppress other individuals; competitive response (CR), or ability to avoid being suppressed; and yield *per se*.

Crop	Reference	Measure of Tolerance
Alfalfa	Hycka, 1976	CE
	Hycka and Benítez-Sídon, 1979	CE
	Bittman et al., 1991	CE, CR
Barley	Anonymous, 1982	CE, CR, yield
	Andersson, 1983	CE
	Siddiqi et al., 1985	CR
Carrot	William and Warren, 1975	CR, yield
Common bean	Barreto, 1970	CR
	Wilson et al., 1980	CE, yield
	Soto and Gamboa, 1984	CE, yield
	Valverde and Araya, 1986	CR
Corn	Staniforth, 1961	CR
	Cadang and Mercado, 1982	CR
	Beale et al., 1983	CR
	Wooley and Smith, 1986	CE
	Callaway, unpublished	CR, yield
Cotton	Weaver et al., 1978	CR, yield
	Chandler and Meredith, 1983	CR, yield
	da Nóbrega et al., 1983	yield
	Bridges and Chandler, 1988	CE, CR, yield
Cowpea	Nangju, 1978	CR, yield
	Remison, 1978	CR
Guineagrass	Monzote et al., 1979	CE

(continued)

tition from late season weeds), or by using the growing season more fully. An example of the latter is early vegetative growth, which suppresses weed competition, followed by later reproductive allocation. Tolerance may also be increased by improving competition for growth factors. Examples include rapid canopy and root system establishment, resulting in improved competition for light, water, and nutrients. Willey and Heath (1969), Donald (1963), and Harper (1977) provide more thorough discussions of mechanisms underlying plant-plant interactions.

To my knowledge, there is no single, sufficiently complete compilation of the widely scattered literature on crop varietal tolerance to weeds, except an earlier unpublished version of this manuscript (Callaway, 1990). I have two aims in writing this paper: to document that varieties differ in tolerance to weeds and that farmers and researchers can exploit these differences; and to provide a guide to the literature for interested researchers. As with any rather untested area of science, among the first questions to be asked is, "Is there evidence that the phenomenon exists?" In this paper I review the work that has been carried out. Breeding and screening methodologies are discussed elsewhere (Callaway and Forcella, in press). I have intentionally ignored the literature on varietal differences in allelopathic weed suppression, because this has been reviewed elsewhere (Rice, 1984; Putnam and Tang, 1986). Breeding for resistance to parasitic weeds also has been reviewed recently (Obilana, 1987;

Table 2. Tolerance assessment using competitive effect (CE), or ability to suppress other individuals; competitive response (CR), or ability to avoid being suppressed; and yield *per se*. (continued)

Crop	Reference	Measure of Tolerance
Lupin	Walton, 1986	CR, yield
Mungbean	Moody, 1978	CR, CE
Peanut	Colvin et al., 1985	CR, yield
	Fiebig et al., 1991	CR, CE, yield
Pigeon pea	Díaz-Rivera et al., 1985	CR, yield
Potato	Würzer, 1967	CE, CR
	Sweet et al., 1974	CE
	Yip et al., 1974	CR
	Duranti and Cuocolo, 1978	CE, yield
	Selleck and Dallyn, 1978	CE
	Nelson and Giles, 1989	CE, CR, yield
Rice	Smith, 1974	CR
	Kawano et al., 1974	CR, CE, yield
	Jones et al., 1979	CE
	Assémat and Oka, 1980	CE, CR, yield
	Ahmed and Hoque, 1981	CR
	Assémat et al., 1981	CE, CR, yield
	Akobundu and Ahissou, 1985	CE, CR
	Diarra et al., 1985	CR, CE
	McGregor et al., 1988	CR, CE
Ryegrass	Charles, 1972	CE
	Gibeault, 1986	CE
Sorghum	Guneyli et al., 1969	CR, CE
	Burnside and Wicks, 1972	CR, CE
Soybean	Staniforth, 1962	CR, CE, yield
	Burnside, 1972	CR, CE
	McWhorter and Hartwig, 1972	CR, yield
	McWhorter and Barrentine, 1975	CR
	Burnside, 1978	CR, CE
	Dowler and Parker, 1978	CE
	Nangju, 1978	CE
	Rose et al., 1984	CR, CE
	Murdock et al., 1986	CR, CE
	James et al., 1988	CR, CE
	Callaway and Forcella, in press	CR, CE
Squash	Stilwell and Sweet, 1974	CR
Sugarcane	Mariotti et al., 1975	CR
	Arévalo et al., 1979	CR
	Millhollon, 1988	CR
	Glaz et al., 1989	CE
Tall fescue	Forcella, 1987	CR, CE

(continued)

Ramaiah, 1987), and is not discussed here. Curiously, the more universal phenomenon of non-allelopathic varietal response to weeds has not been reviewed previously.

Varietal Tolerance in Cereal Grains

Barley (Hordeum vulgare)

In field trials of sixteen to twenty varieties, weed dry weight ranged from 45 g/m^2 in 'Nordal' to 130 g/m^2 in 'Hood' (Anonymous, 1982). Weed dry weight was negatively correlated with crop dry weight and grain yield. High yielding varieties also were high yielding in weed-free plots, while varieties yielding poorly in the presence of weeds also yielded poorly under weed-free conditions. Intraspecific competitive ability (among varieties) appeared to be controlled by the same physiological processes that determine interspecific competitive ability (against weeds).

Siddiqi et al. (1985) noted substantial differences for efficiency of potassium use among eight varieties in the presence of a genetically pure line, 'CS40', of wild oat (*Avena fatua*). 'Fergus' was highly competitive (little loss in dry weight) with wild oat at both high and low potassium ion concentrations, while 'Steptoe' was competitive only at high concentrations.

Andersson (1983) evaluated eight varieties of barley, three of spring wheat, and five of oats for their competitive ability with weeds as measured by the average plot weight of weeds. The best competitors had the highest stem weights.

Corn (Zea mays)

Staniforth (1961) evaluated four hybrids in the presence of yellow foxtail (*Setaria lutescens*) at three nitrogen (N) levels. Over all N levels, yield reduction per hundredweight of foxtail was consistently highest for the late maturing hybrid 'AES 801' and generally lowest for the early maturing hybrid 'Ia 4630', suggesting that "the early maturing hybrid was past a critical period in its growth before the onset of severe foxtail competition."

In pot experiments, Cadang and Mercado (1982) ranked six varieties' sensi-

Table 2. Tolerance assessment using competitive effect (CE), or ability to suppress other individuals; competitive response (CR), or ability to avoid being suppressed; and yield *per se*. (continued)

Crop	Reference	Measure of Tolerance
Wheat	Appleby et al., 1976	CR, yield
	Blackshaw et al., 1981	CR
	Kirichenko et al., 1982	CE
	Kreuz, 1982	CR
	Challaiah et al., 1983	CE, yield
	Flood and Halloran, 1984	CR
	Kreuz et al., 1984	CR
	Lyfenko et al., 1984	CE
	Ramsel et al., 1984	CE
	Sechnyak et al., 1985	CE
	Challaiah et al., 1986	CR, CE
	Wicks et al., 1986	CE
	González-Ponce, 1988	CR, CE
	Ramsel and Wicks, 1988	CE
	Balyan et al., 1991	CR, CE, yield

tivity to competition with *Ipomoea triloba*. The highest yielders suffered the greatest yield reduction (52-75% of weed-free) and the lowest yielders the least (15-24% of weed-free).

In a test not intended to compare varietal tolerance to weeds, Beale et al. (1983) reported yields of four varieties in plots receiving three different herbicide treatments and in unweeded check plots. When each variety's performance in unweeded plots was compared to its best performance with herbicides, 'Merit' suffered much less reduction than the other varieties in number of ears per acre (53% for 'Merit' vs. 69-75% for the others), weight per acre (57% vs. 68-72%), and weight per ear (1% vs. 13-20%).

Table 3. Crop characteristics influencing tolerance to weeds.

Characteristic	Selected References
Seedling Establishment	
Large average seed weight	Valverde and Araya, 1986
Rapid emergence	Guneyli et al., 1969; Rose et al., 1984; Yip et al., 1974
High seedling growth rate	Challaiah et al., 1983; Guneyli et al., 1969
Decreased vernalization response	Flood and Halloran, 1984
Canopy Characteristics	
Rapid canopy formation	Rose et al., 1984; Yip et al., 1974
Large canopy diameter	Challaiah et al., 1986
Maintenance of dense canopy	Yip et al., 1974
High leaf area index	Jones et al., 1979; Kawano et al., 1974; Lyfenko et al., 1984; Moody, 1978; Nangju, 1978; Sechnyak et al., 1985
Much axillary branching	Challaiah et al., 1983; Challaiah et al., 1986; Kreuz, 1982
Plant Height and Maturity	
Tall plant height	Ahmed and Hoque, 1981; Blackshaw et al., 1981; Challaiah et al., 1986; DeDatta et al., 1969; Jones et al., 1979; Kirichenko et al., 1982; Lyfenko et al., 1984; Monzote et al., 1979; Nangju, 1978; Sechnyak et al., 1985; Wicks et al., 1986
High plant height index	Challaiah et al., 1983
Indeterminate growth habit	Baretto, 1970; Remison, 1978; Stilwell and Sweet, 1974; Wilson et al., 1980
Bush habit	Stilwell and Sweet, 1974
Later maturity	Barreto, 1970; Dowler and Parker, 1978; Rose et al., 1984; Smith, 1974
Earlier maturity	Hycka and Benítez-Sidon, 1979; Staniforth, 1961
Vigor and Productivity	
High yield	Hycka and Benítez-Sidon, 1979; Wicks et al., 1986
High dry weight production	Anonymous, 1982; Challaiah et al., 1983
Large number of pods per plant	Valverde and Araya, 1986
Good intraspecific competitive ability	Anonymous, 1982; Kawano et al., 1974
Use of Nutrients	
High rate of nitrogen absorption	Kawano et al., 1974
Efficient potassium utilization	Siddiqi et al., 1985

Wooley and Smith (1986) found that plots of four corn varieties differing in phenologies ranged in weed cover from 38% ('PB6') to 73% ('BC2'). Weed cover tended to decrease with increasing leaf area index (LAI) and plant height.

Callaway (unpublished) examined the responses of three corn hybrids to competition from weeds (primarily *Cyperus* spp.). 'Pioneer 3165', 'Dekalb 689', and 'B73/Mo17' were grown alone and in 50% and 33% mixtures with the other hybrids under weedy and weed-free conditions. 'Pioneer 3165' was the highest yielding hybrid in weedy or weed-free conditions. The effects of combining hybrids into mixtures were additive.

Rice (Oryza sativa)

Smith (1974) evaluated the ability of three varieties to compete with barnyardgrass (*Echinocloa crus-galli*). Significant yield reduction in 'Nova 66' and 'Bluebelle' occurred after 40 days of competition. 'Starbonnet' yields were significantly reduced by competition for 60 days or more. Yield losses were not due to plant height or reduced yield per head; however, competitive ability increased with maturity.

Of three varieties studied, Ahmed and Hoque (1981) found yield reduction to be least in the tallest variety, 'Nizersail' (0.25 t/ha), intermediate in the variety of intermediate height, 'BR4' (0.46 t/ha), and greatest in the shortest variety, 'BR6' (0.68 t/ha). A second study involving three different varieties showed a similar pattern (Ahmed and Hoque, 1981). Yield reduction was least in the tallest variety, 'Habiganj Boro VI' (0.42 t/ha), intermediate in the variety of intermediate height, 'BR9' (0.66 t/ha), and greatest in the shortest variety, 'Chandina' (0.95 t/ha). These results indicate that plant height and proportional yield reduction are negatively correlated.

In a study involving 25 varieties, Kawano et al. (1974) found intraspecific competition and spacing response to be highly correlated with ability to compete with weeds. Important characteristics were high vegetative vigor, large leaf area, and high rate of N absorption in the early stages of growth. More specifically, plant weight at an early stage of growth and plant height were most highly correlated (positively) with competitive ability, while tillering was not important. The correlation between competitive ability and grain yield was influenced by the farming system used. Competitive ability was positively correlated with grain yield at wide row spacing and low N, but was negatively correlated with grain yield under conditions of high density, high N, and clean weeding. Therefore, Kawano et al. (1974) concluded that a breeder would want different plant types for different farming systems.

Jones et al. (1979) used three varieties differing in height and tillering ability to determine the minimum combination of plant height and LAI necessary to reduce photosynthetically active radiation (PAR) at the soil surface by 85 to 95%, thereby inhibiting weed growth. At wide spacing, erect varieties that provided a canopy depth of approximately 100 cm and an LAI of 3.0 to 3.6 reduced inter-row PAR by the desired amount. Varieties with an LAI of 3.9 to 4.6 produced the same shade with a canopy height of 25 cm.

Assémat and Oka (1980) and Assémat et al. (1981) used two strains of rice and two of barnyardgrass to explore mechanisms for differential interactions among genotypes of different species. They found that density, shoot, and root effects were important.

Akobundu and Ahissou (1985) evaluated response to weed competition in three varieties differing in height. Lowest weed weights were found with 'Adny 11', which tillers profusely. However, 'Adny 11', the shortest of the three, suffered the greatest yield reduction from weed competition at the wide row spacings traditionally used by farmers.

In another study, involving two varieties (McGregor et al., 1988), yield was reduced less in 'Mars,' a variety that reduced weed (*Brachiaria platyphylla*) dry weight more than 'Lebonet'. 'Mars' also was a better competitor with red rice (*Oryza sativa*) than 'Lebonnet' (Diarra et al., 1985).

Sorghum (Sorghum bicolor)

Guneyli et al. (1969) evaluated 48 hybrids and 41 parental lines under greenhouse and field conditions. Hybrids generally were better than parental lines in competing with weeds. 'SD 441', 'RS 609', 'OK 613', 'TX 660', and 'KS 602' were most competitive with weeds and had the lowest yield loss. Competitive advantage was attributable largely to rapid germination, early emergence, and root and shoot growth during early development. Of ten hybrids studied by Burnside and Wicks (1972), the three exhibiting the lowest proportional yield reduction also caused the highest proportional reduction in weed growth. Those exhibiting greatest proportional reduction in yield were not necessarily the ones allowing the most weed growth. Weeding for the entire season, rather than the first three weeks after planting, resulted in significantly lower weed growth for only three hybrids.

Wheat (Triticum aestivum)

Of the crops evaluated for varietal tolerance to weeds, wheat has perhaps received the greatest research attention. Blackshaw et al. (1981) evaluated a semidwarf variety of spring wheat, 'Norquay', and two normal varieties, 'Napayo' and 'Sinton'. They included different densities of green foxtail (*Setaria viridis*) and different seeding dates for wheat. On the basis of proportional reduction in wheat yield, 'Norquay' was less tolerant of weeds than 'Sinton'. The shorter plant presumably shaded the weeds less. Challaiah et al. (1983) evaluated 85 winter wheat varieties using weed numbers as the criterion for competitive ability. At similar weed populations, some varieties had significantly greater yields than the widely grown 'Centurk 78'. More weeds emerged in varieties that intercepted less light. Characteristics improving the competitive ability of wheat were higher tiller number, plant height, plant height index (PHI), dry weight, and seedling growth rate. Challaiah et al. (1986) reported nine winter wheat varieties' tolerance to downy brome (*Bromus tectorum*), based on weed dry weight. Height was the most important characteristic, although canopy diameter and tiller number also were important. Grain yield ranking was similar in weedy and weed-free plots. These workers suggested three criteria for selecting weed-tolerant varieties: lowest weed growth, low grain yield reduction, and tall plants. Flood and Halloran (1984) evaluated differences in weed tolerance among four lines of

'Triple Dirk' that were near-isogenic for vernalization response. There was a non-significant pattern of progressive decrease in grain weight per plot with increasing vernalization response. Ramsel et al. (1984) found that winter wheat varieties 'Centurk 78', 'Tam 101', and 'Vena' suppressed weeds more than 'Buckskin', 'Eagle', and 'Bennett'; however, differences in weed control were not apparent two months after harvest. Wicks et al. (1986) evaluated twenty winter wheat varieties and found that those taller than 83 cm usually were the best competitors. However, two of the shortest varieties, 'NE78742' (75 cm) and 'NE78743' (72 cm) also were among the best competitors. Competitive ability was based on visual ratings of weed control and on weed dry weight. Weed control ranged from 59 to 96%, and was positively correlated with grain yield and plant height. Differences were observed between sources of varieties. Selections from Lancota germplasm were competitive, while those from Homestead germplasm were among the poorest competitors.

Significant differences in ability to limit densities of barnyardgrass were found among six winter wheat varieties (Ramsel and Wicks, 1988). These differences could not be attributed to either plant height or light interception.

Over six years, Kreuz (1982) found differences in yield reduction from weeds among four varieties of winter wheat. Yield of 'Alcedo', a high tillering variety, was reduced less than yields of 'Il'ichevka', which produces large ears. In a later study, Kreuz et al. (1984) again found 'Alcedo' to suffer less from weeds than three other varieties.

In three reports involving winter wheat varieties, 'Stepnyak' was the most competitive (Kirichenko et al., 1982; Lyfenko et al., 1984; and Sechnyak et al., 1985). In each of these studies, short varieties were compared with tall varieties, and in each case short varieties were less competitive. However, it was possible to identify superior varieties among the short types, such as 'Brigantina' and 'Yuzhnaya Zarya' (Kirichenko et al., 1982; Lyfenko et al., 1984). Competitive ability was based on ability to suppress weed weight. Important selection criteria were LAI at stem elongation and horizontal leaf arrangement.

Appleby et al. (1976) reported differences among four varieties' tolerance to Italian ryegrass (*Lolium multiflorum*). Proportional yield reduction tended to be higher in shorter varieties ('Nugaines' and 'Hyslop') and lower in taller varieties ('Druchamp' and 'Yamhill'). They concluded that where ryegrass is expected to be a problem, the use of taller varieties may be advisable, especially if their yield potential is high under nonweedy conditions.

Balyan et al. (1991) examined five varieties' response to competition from wild oat (*Avena ludoviciana*). 'WH-147' and 'HD-2285' were the most competitive varieties, as measured by reduction in wild oat dry matter. The two highest-yielding varieties under weed-free conditions, 'HD-2009' and 'WH-147', differed greatly in the fraction of weed-free yield maintained under weedy conditions. 'WH-147' had the second highest weed-free yield (6884 kg/ha) and the highest yield under weedy conditions (5044 kg/ha). 'HD-2009' had the highest weed-free yield (6948 kg/ha) but produced only 40% of that amount under weedy conditions (2794 kg/ha), becoming the lowest yielding variety. Wheat height and dry matter accumulation during early growth were good predictors of tolerance to wild oat.

Under greenhouse conditions, González-Ponce (1988) studied the interaction of *Avena sterilis* ssp. *macrocarpa* with varieties differing in their growth cycles. All varieties had similar effects on *A. sterilis*. However, the varieties were affected differentially by the weed. 'Estrella' had the longest growth cycle and was most affected by the weed.

Varietal Tolerance in Grain Legumes

Common bean (*Phaseolus vulgaris*)

Barreto (1970) examined how five varieties with different growth habits responded to weeds and periods of competition. Highly significant responses were observed for varieties, periods of competition, and variety by period interaction. Later maturing, indeterminate varieties exhibited greater weed tolerance than early, bush types. The author suggested that this may be due to competition for light. Wilson et al. (1980) compared the response of an indeterminant variety, 'Tara', with a bush type, 'Great Northern 1140'. Total weed growth was higher in 'Tara' plots (2560 vs. 2480 kg/ha for 'Great Northern 1140'); however, 'Tara' outyielded 'Great Northern 1140' under weed-free and weedy conditions. Two varieties evaluated by Soto and Gamboa (1984) were similar in maturity (85-90 days) but had somewhat different growth habits: 'Talamanca' is Type IIA and 'ICA-Pijao' is Type IIB. (See CIAT [1980] or Davis et al. [1984] for descriptions of growth habit types in beans.) Lower weed fresh weight and higher bean yield were found in plots of 'ICA-Pijao' than in 'Talamanca'. The authors concluded that the superiority of 'ICA-Pijao' was due largely to greater axial development (more branching), which provides a denser canopy and more thorough shading of the soil. Valverde and Araya (1986) examined how the yield components of six varieties responded to weeds. The number of pods per plant and average seed weight were significantly and positively correlated with yield. 'ICA-Pijao', 'Bat-202' and 'Rev. 79' gave the most stable yields, that is, lower yield variation between weedy and weed-free conditions, indicating tolerance to weeds.

Cowpea (*Vigna unguiculata*)

Of four varieties evaluated by Remison (1978), yield of a climbing variety, 'Dinner', was least affected by weeds (36% reduction); yield of a semi-erect variety, 'Ife', was most affected (64% reduction). 'Prima', an erect, early maturing variety and 'Mala', a prostrate, late maturing variety, were intermediately affected. All varieties were indeterminant types. There were significant interactions between variety and weed competition in determining pod weight and seed weight. The rank of the four varieties for grain yield was 'Ife' > 'Dinner' > 'Prima' > 'Mala'.

Nangju (1978) evaluated four varieties differing in growth habit. Competitive ability (CR) improved with taller plants, high LAI, and certain leaf shapes and sizes.

For example, the strap leaf 'TVx 33-16' was less competitive than other varieties with similar LAIs.

Mungbean (Vigna radiata)

Yield reduction of 'CES14' was the lowest (73%) of five varieties subjected to full-season weed competition (Moody, 1978). Yield of 'BPI Glabrous 3' was reduced by 96%, but this variety also reduced weed dry weight the most. LAI was inversely related to weed dry weight for all varieties except 'CES14'.

Peanut (Arachis hypogaea)

Colvin et al. (1985) evaluated 'Florunner', a later maturing runner type variety, and 'Pronto', an earlier maturing upright type. 'Florunner' outyielded 'Pronto' regardless of weed management used. However, under weedy conditions, yield of 'Florunner' was only about half its best weed-free yield, while 'Pronto' yielded about three-fourths of its best weed-free yield. In another study (Fiebig et al., 1991), 'NC 7' had the highest weed-free yield and greatest weed suppression of four varieties studied. Under the most weedy conditions, 'NC 7' had the lowest yields. 'F8143B' generally sustained lower proportional yield losses under weedy conditions, while 'BL-10' generally had the highest yield under weedy conditions. Longer vegetative development and lower rate of partitioning to pods were suggested as important for peanuts to avoid competition from determinate, photoperiod-sensitive weeds. Although these characteristics may be associated with reduced weed-free yields, the magnitude of differences in pod yield losses led Fiebig et al. (1991) to conclude that there was potential for developing peanut varieties with improved tolerance to weeds.

Pigeon pea (Cajanus cajan)

Díaz-Rivera et al. (1985) compared critical weed-free periods for the varieties 'Kaki' and '2B-Bushy'. 'Kaki' had higher yields and tolerated weed competition without yield loss for seven days longer than '2B-Bushy'. The dominant weeds were *Amaranthus dubius, Cleome gynandra, Digitaria sanguinalis, Echinocloa colona*, and *Leptochloa filiformis*.

Soybean (Glycine max)

Staniforth (1962) examined four varieties, all but two having differing maturities. No differences in weed tolerance were observed. Of ten varieties evaluated by Burnside (1972), all suffered large yield reductions (41 to 52%) in plots receiving no weed control. Plots weeded for the first three weeks after planting had 74% fewer weeds than unweeded plots. Under these conditions of intermediate weed pressure, 'Harosoy 63', 'Amsoy', and 'Corsoy' exhibited the lowest proportional yield losses (3, 6, and 9%, respectively), while 'Hawkeye 63', 'Shelby', and 'Lindarin 63' had the greatest (20, 17, and 16%, respectively). 'Harosoy 63', 'Corsoy', and 'Shelby' plots had the lowest weed biomass. Weed suppression by the variety 'Hark' depended on the timing of weed control. 'Hark' had the highest weed growth in totally unweeded plots (2850 kg/ha), but was among the varieties having the lowest amount of weed growth (240 kg/ha) in plots receiving three weeks of handweeding.

McWhorter and Hartwig (1972) evaluated the tolerance of six soybean varieties to johnsongrass (*Sorghum halepense*) and cocklebur (*Xanthium strumarium*). 'Bragg' generally had the highest yield in the presence of johnsongrass and 'Semmes' the highest in the presence of cocklebur. Average yield reductions (over years) from johnsongrass ranged from 23% to 42%, depending on variety and harvest method. Higher average reductions (36 to 75%) were observed in competition with cocklebur. In a separate study, 'Bragg' was the most competitive with cocklebur of five varieties, including 'Semmes' (McWhorter and Barrentine, 1975).

Burnside (1978) found 'Amsoy 71' to be more effective in reducing weed growth than 'Beeson'. He noted that 'Amsoy 71' maintained its weed-free seed size under weedy conditions, while seed size in 'Beeson' decreased in the presence of weeds. In another comparison of two varieties, Dowler and Parker (1978) found more weeds in the early maturing 'Coker 136' than the later maturing 'Hutton'. Of three varieties evaluated by Nangju (1978), 'Williams' had shorter height, earlier maturity, and lower LAI, and less weed weight than 'Bossier' and 'Jupiter'. Weed weight was negatively correlated with LAI.

Rose et al. (1984) initially screened 280 accessions for weed tolerance. From these, twenty were selected for further study. Competitive ability (weed tolerance) generally increased with increasing maturity. These authors suggested that the later maturing accessions had better seed quality, which increased their germination rate and vigor.

Three varieties, 'Ransom', 'Govan', and 'Bragg', were evaluated in association with pitted morning glory (*Ipomoea lacunosa*) (Murdock et al., 1986). These varieties did not differ in their ability to suppress dry weight of pitted morning glory, even though 'Ransom' shaded the soil later than the other two. Pitted morning glory affected yields of the three varieties differently in one year of the two-year study. In that year, 'Govan', 'Bragg', and 'Ransom' required 0, 2, and 4 weed-free weeks, respectively, for maximum yields.

James et al. (1988) studied the responses of twelve varieties grown with sicklepod (*Cassia obtusifolia*). Maturity group and date of introduction were not correlated with ability to compete with sicklepod. 'Essex' and 'Bragg' significantly reduced weed dry weight. Cultivars with lower weed-free dry weights suffered smaller relative weight loss in competition with sicklepod than did those that produced greater weed-free dry weights.

Callaway and Forcella (in press) describe a selection experiment to improve crop tolerance (CE and CR) to weeds using two varieties, 'Gnome' and 'Evans', which are considered to have high and low competitive ability, respectively. These varieties were crossed, and their progenies selected for three generations for leaf area per plant, which was correlated with weed biomass. One selected line, 'L26', had an appreciably higher competitive ability than 'Evans'. They concluded that competitive ability may be improved while maintaining or improving yield.

Varietal Tolerance in Forages

Alfalfa (*Medicago sativa*)

Four varieties were compared with the ecotype 'Aragón' by Hycka and Benítez-Sídon (1979). 'Aragón' was the earliest, had the highest mean forage yield, and was most resistant to weed invasion. In another study, Hycka (1976) identified 'Ampurdán' as most resistant to weed invasion. Bittman et al. (1991) concluded that alfalfa variety significantly affected the proportion of weeds in harvested yield. Of seven varieties tested, 'Beaver' had a significantly higher proportion of weeds (7.9%) over the 5-year study than any other variety except 'Drylander' (6.7%). 'ScMf3713' had a significantly lower proportion of weeds (4.9%) than either 'Beaver' or 'Drylander'. All other differences were not statistically significantly.

Guineagrass (*Panicum maximum*)

Of seventeen varieties studied, 'Coloratum' was the tallest and the least weed infested (Monzote et al., 1979).

Lupin (*Lupinus angustifolius*)

Two lupin varieties, 'Illyarrie' and 'Marri', were seeded with and without simazine for weed control. 'Illyarrie' had higher yields in weedy (1125 vs. 717 kg/ha) and weed-free (simazine treated) (1337 vs. 1004 kg/ha) conditions and a lower reduction in yield (16 vs. 29%) than did 'Marri' (Walton, 1986).

Ryegrass (*Lolium perenne*)

Charles (1972) found that a "survivor" ryegrass population was much more successful in excluding *Poa trivialis* (a weed here) than were two ryegrass varieties. From research with 37 varieties of ryegrass, Gibeault (1986) concluded that turfgrass varieties that perform best in quality evaluations usually have the least weed invasion.

Tall fescue (*Festuca arundinacea*)

In a study of two near-isogenic genotypes, Forcella (1987) concluded that high leaf area expansion rate confers weed tolerance and competitive ability. He further suggested that genes conferring high leaf area expansion rate be used in breeding programs to improve varietal tolerance to weeds.

Varietal Tolerance in Other Crops

Carrot (*Daucus carota*)

William and Warren (1975) reported on differences in tolerance to competition from purple nutsedge (*Cyperus rotundus*) for two carrot varieties, 'Nantes' and 'Kuroda'. 'Kuroda', a taller more robust variety, suffered a smaller proportional yield loss (39%) from purple nutsedge than did 'Nantes' (50%). Nevertheless, 'Nantes' outyielded 'Kuroda' in weedy (2.1 vs. 0.9 kg/m^2) and weed-free (4.1 vs. 1.4 kg/m^2) conditions.

Cotton (*Gossypium hirsutum var. latifolium*)

In two separate studies (da Nóbrega et al., 1983; Bridges and Chandler, 1988), no statistically significant differences were observed among varieties in their ability to compete with weeds. However, Chandler and Meredith (1983) concluded that 'Deltapine 16' was more competitive (less yield decrease) with spurred anoda (*Anoda cristata*) than was 'DES 21326-04' or 'Stoneville 213'. However, 'DES 21326-04' yields were significantly higher than the other two varieties when averaged over all spurred anoda competition levels. Weaver et al. (1978) also reported varietal differences in response to weeds. In 1975, a low-yield year for cotton, 'Louisiana Super Okra' had substantially higher yield (276 kg/ha) in the zero-herbicide treatments than did 'Coker 310' (191 kg/ha) or an interspecific hybrid (173 kg/ha). The following year, when yields were near normal for the area, 'Coker 310' had the highest yield (727 kg/ha) and 'Louisiana Super Okra' the lowest (530 kg/ha). Zero-herbicide yield was approximately 80-90% of the best yield with herbicide for all varieties in both years, except 'Coker 310' in 1975, when it was 57% of the best yield.

Potato (*Solanum tuberosum*)

Work at Cornell University (Sweet et al., 1974; Yip et al., 1974; Selleck and Dallyn, 1978) demonstrated varietal differences in tolerance to weeds. 'Green Mountain' and 'Norchip' were competitive (CR) with broadleaf weeds and yellow nutsedge (*Cyperus esculentus*) (Yip et al., 1974). 'Hudson' competed well with yellow nutsedge but was not included in tests with broadleaves. 'Katahdin' and 'Sebago' were least tolerant and suffered significant yield losses. Competitive ability was associated with early emergence, rapid early growth, and the ability to maintain a dense canopy throughout the growing season. Sweet et al. (1974) reported high, positive correlations between weed suppression and light interception by the potato canopy. Selleck and Dallyn (1978) found 'Katahdin' and 'Hudson' to be most effective of six varieties in their ability to suppress weeds. The control of barnyardgrass without herbicides in 'Katahdin' and 'Hudson' approached that of 'Superior' with herbicides. The apparent discrepancy between Yip et al. (1974) and Selleck and Dallyn (1978), who, respectively, classified 'Katahdin' as least effective and most effective in its ability to compete with weeds, may be explained by three important differences between the studies. First, other than 'Katahdin', the only variety common to both studies was 'Hudson', which was evaluated only in one test conducted by Yip et al.; therefore the two groups compared 'Katahdin' to different varieties. Second, potato varieties were evaluated in different weed associations. The weed community consisted mainly of barnyardgrass and ladysthumb (*Polygonum persicaria*) in one study (Selleck and Dallyn, 1978), and either redroot pigweed (*Amaranthus retroflexus*) and lambsquarters (*Chenopodium album*) or yellow nutsedge in the other (Yip et al., 1974). Third, different measures of competitive ability

were used in the two studies: Selleck and Dallyn emphasized CE, while Yip et al. emphasized CR.

Of five varieties tested by Duranti and Cuocolo (1978), 'Spunta' and 'Majestic' allowed the greatest weed development. Nevertheless, 'Majestic' had the highest tuber yield while 'Tonda d'Angri', which allowed the least weed development, had the lowest tuber yield. Würzer (1967) observed that five varieties differed markedly in the quantity of weeds two years after the varieties were grown. These differences were apparent even though there had been no differences in yield reductions from weeds when the varieties originally were grown. Nelson and Giles (1989) studied two varieties, 'Red Norland', which is early and small-vined, and the late, large-vined 'Red Pontiac'. Over two years, plots of 'Red Norland' contained an average of 59% more weeds than 'Red Pontiac'. These two varieties had similar yields under weed-free conditions, but in weedy conditions, yields were 35 and 55% of weed-free yields for 'Red Norland' and 'Red Pontiac', respectively.

Squash (Cucurbita pepo)

Stilwell and Sweet (1974) compared the responses of three winter squash varieties to broadleaf weeds and yellow nutsedge competition. 'Ebony Acorn', a vining type, gave 91% of its weed-free yield when planted early and in the presence of broadleaf weeds. If planted late, it produced only 31% of its weed-free yield. The two other varieties, 'Table Queen Bush', a non-vining type, and 'Bush Ebony', which is compact when young, becoming vining at maturity, were less tolerant to broadleaf weed competition, yielding 16% to 24% of weed-free yield, depending on planting date. However, they competed well against yellow nutsedge when planted late; yields of 'Table Queen Bush' and 'Bush Ebony' were 84 and 87%, respectively, of their yields under "weed-free" conditions (less than 10 yellow nutsedge shoots per m^2), vs. only 68% for 'Ebony Acorn'.

Sugarcane (Saccharum spp.)

Of seven varieties evaluated (Arévalo et al., 1979), 'NCo310' was found to be tolerant (CR) to *Cyperus rotundus*. 'NCo310' and 'NA56-79' were tolerant to natural communities of weeds and to johnsongrass. These were the only two varieties in which sugar yield was not reduced by increased weed competition.

Mariotti et al. (1975), who tested 100 genotypes, mentioned that varieties selected as superior genotypes from weed-free experiment station conditions often have inferior performance (CR) in the weedier conditions of farmers' fields.

Millhollon (1988) evaluated the responses of five sugarcane varieties to johnsongrass competition. Yield as a fraction of weed-free yield ranged from 44 to 86% in the first harvest, and from 12 to 49% in the ratoon harvest. Lower yields in 'NCo310' and 'CP 48-103' were attributed to their less effective competition with johnsongrass compared to the other varieties.

Glaz et al. (1989) stated that fast-growing varieties often are used to control weeds in sugarcane. Among three varieties differing in growth rates, they found no significant relation between variety and level of weed control. However, they pointed out that the predominant weeds in this study were prostrate or of short stature.

Summary

Varietal differences in tolerance to weeds have been observed in all crops examined in this review, even though most reports evaluated fewer than ten varieties. Several plant characteristics have been identified or suggested as improving weed tolerance (Table 3). Certain characteristics may be associated with increased weed tolerance for certain crop species and cropping situations. The same characteristics may have a neutral or even negative effect on weed tolerance for other crop species or cropping situations. Later maturity, for example, was important in increasing weed tolerance of common bean (Barreto, 1970) and rice (Smith, 1974), but early maturity increased weed tolerance in corn (Staniforth, 1961). Other characteristics seem much more universally associated with increased weed tolerance. These include tallness, high LAI, and rapid canopy formation.

Several objections to improving varietal tolerance to weeds have been raised. I briefly considered these in light of the present literature review.

1. *With enough inputs the crop doesn't suffer from competition with weeds.*

This may be true when the crop is more responsive to the input than the weed. However, this is not always so. In a study by Staniforth (1962), residual N fertilizer stimulated a growth response from weeds, but no corresponding response from the soybean crop. There, a higher level of an input (N fertilizer) reduced crop yield.

2. *Selection of weed tolerant genotypes is too complex.*

Many examples of weed tolerant, agronomically acceptable varieties are given in this review (for example, Challaiah et al., 1983; Yip et al., 1974). Specific characteristics of medium to high heritability have been identified that confer improved weed tolerance (e.g., Gunelyi et al., 1969; Rose et al., 1984; Challaiah et al., 1986). Callaway and Forcella (in press) provide a case study of improved weed tolerance in soybean. Other crops may require drastic deviations from an agronomically acceptable plant type to exploit differences in weed tolerance. Therefore, the incorporation of weed tolerance may be counterproductive. (See Jennings and Aquino [1968] and DeDatta et al. [1969] for examples in rice.)

3. *Breeding for weed tolerance does not deserve research effort as much as increased yield, disease resistance, and other crop characteristics.*

Rhodes et al. (1985) stated that "annual losses in crop yield and quality due to weeds, combined with the costs of weed control, are greater in the United States than those due to insects, plant diseases, and nematodes combined." If a small fraction of the time and expense devoted to weed control could be avoided, this would mean great savings. Besides the immediate economic costs, environmental costs could

be reduced if the number of cultivations and herbicide applications required to produce a crop could be reduced.

4. *High yielding varieties are inherently more tolerant of weed competition.*

and

5. *Weed tolerant varieties are poor yielders and of poor agronomic type.*

Examples supporting both these contradictory generalizations are found in this review. Kawano et al. (1974) found that the relationship between tolerance and yield depended on the cropping system.

6. *All weeds must be eliminated because they provide seed for future infestations.*

Agronomic, economic, and environmental costs must be considered together to determine acceptable short-term and long-term levels of weed infestation. Generally, elimination of all weeds will probably not be sensible.

7. *Separate selection is required for each important weed species.*

It may be possible to group weed species into competitive equivalents so that selection pressure and crop tolerance is more easily quantified (Goldberg and Werner, 1983; Goldberg and Landa, 1991; Pantone and Baker, 1991). Callaway and Forcella (in press) provide a detailed discussion of methods for achieving this.

In summary, many objections to breeding crops for tolerance to weeds are based on generalizations, not on the available evidence. Examples in this review should provide a more rational basis for determining how much crop tolerance to weeds can be improved.

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Natural Food Supermarket Chain is "Store of the Year"

Fresh Fields, a small supermarket chain in the Washington, D.C. area that specializes in organic, drug-free, and natural foods, has been named *Money* magazine's "1993 Store of the Year" by "riding the crest of a mighty trend—eating for health." Fresh Fields' stores are as large as many supermarkets; their aisles feature thousands of ordinary supermarket items with a healthy twist, such as chemical-free ground beef, organic baby food, and hormone-free low-fat milk.

Its rules allow no foods with refined sugars or synthetic preservatives, and no meats from animals grown with hormones or antibiotics. "The good-for-you premium at Fresh Fields is only 5% or so," the magazine says, pointing out that in-season locally grown organic produce costs less at Fresh Fields than in-season nonorganic produce at nearby supermarkets.

Agricultural use of organic amendments: A historical perspective

James F. Parr and Sharon B. Hornick

Abstract: *Agricultural research conducted in the United States since establishment of the U.S. Dept. of Agriculture and Land-Grant University System in 1862 has shown that regular and proper additions of organic materials are very important for maintaining the tilth, fertility, and productivity of agricultural soils, protecting them from wind and water erosion, and preventing nutrient losses by runoff and leaching. Several millennia earlier, Roman agriculturists were advocating crop rotations, green manuring, composts, legumes, farmyard manures, crop residues, wood ashes, seaweed, and sewage wastes for supplying humus and nutrients to restore or enhance soil productivity. Even earlier, Asian farmers also used these practices to maintain healthy and productive soils. Today the most serious problem in U.S. agriculture and agriculture worldwide is the widespread degradation of agricultural soils through erosion and the consequential decline in productivity. In view of how much information is available on the benefits of organic recycling on agricultural lands, one wonders why we aren't doing a better job of protecting and conserving our land resource base. We discuss strategies for using organic resources more effectively to achieve a more sustainable agriculture for the future.*

Key words: early agriculture, soil organic matter, erosion, soil quality, best management practices, municipal solid waste, sewage sludge, composting

Most books on soil and crop husbandry written in the United States during the past 100 years extol the virtues of soil organic matter, soil conservation, crop residue management, animal manuring, green manuring, cover crops, and crop rotations. They often refer to scientific research conducted by the U.S. Department of Agriculture and Land-Grant Universities, both established in 1862, that show that regular additions of organic amendments such as crop residues, animal manures, and green manures are essential for maintaining the tilth, fertility, and productivity of soils, for protecting them from wind and water erosion, and for preventing nutrient losses through runoff and leaching. The beneficial effects of these materials for improving the chemical, physical, and biological properties of agricultural soils have been extensively documented (U.S. Dept. of Agriculture, 1957, 1978, 1980; Allison, 1973; Hornick and Parr, 1987; Parr and Colacicco, 1987; Reganold et al., 1990).

Interestingly, many practices involving organic amendments, which we now call "best management practices," originated with early farmers about 2000 B.C. Such practices have been perfected down through the centuries as simple but powerful tools that could enhance agricultural sustainability indefinitely. It is ironic that as we approach the year 2000 A.D., the most serious threat to agriculture, both nationally and worldwide, is the continuing and alarming rate of soil degradation by wind and water erosion, and the concomitant loss of soil productivity.

Throughout this paper we use the term "organic amendment" for a wide array of organic materials, wastes, and residuals of either rural or urban origin that can improve soil properties and plant growth, and impart such beneficial effects over time that will improve soil productivity (U.S. Dept. of Agriculture, 1957). We offer a historical perspective on agricultural use of organic amendments, discuss the reasons for our current dilemma, and propose some strategies to enhance the value and effectiveness of these amendments as soil conditioners and organic fertilizers, that is, biofertilizers.

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Early Developments

The Fertile Crescent

Scientists who have studied the origin of agriculture generally agree that it first began in the Near East about 8000 B.C. on a curving strip of land extending north through parts of Iran and Iraq, westward across northern Syria and southeastern Turkey, and southward through Lebanon and Israel and into the Nile Valley. This region has been referred to through the centuries as the Fertile Crescent. It was here that hunter-gatherers started to domesticate sheep and goats and began to cultivate the wild wheat and barley that abounded in this region (Leonard, 1973). Table 1 lists some significant events in the evolution of organized agriculture since then. Only a few significant milestones will be discussed here to emphasize how important it was to early farmers to regenerate their soils with organic amendments and residuals.

Farmers of forty centuries

Table 1 shows that farming began to develop in China, Mexico, and Peru between 4000 and 3000 B.C. In the early

1900s, F.H. King, Chief of the Division of Soil Management, U.S. Dept. of Agriculture, became concerned about the sustainability of farming practices in the United States and whether we could maintain our soils' fertility and productivity for future generations. He was curious how farmers in the Far East did this despite such high population densities. In 1911, he traveled extensively in China, Korea, and Japan. In King's own words:

> We desired to learn how it is possible after twenty and perhaps thirty or even forty centuries, for their soils to be made to produce sufficiently for the maintenance of such dense populations as are living now in these three countries. (King, 1911, p. 2)

King found that the key to maintaining a permanent and sustainable agriculture through the centuries in China, Korea and Japan was the regular and extensive recycling of a vast array of organic materials as soil conditioners and biofertilizers. These materials included animal manures, green manures, nightsoil, crop residues, canal mud, wood ashes, tree leaves, aquatic weeds from canals, wild grasses, urban sewage and street refuse. Many of these materials were composted to destroy weed seeds and potential human and plant pathogens, to enhance their nutrient availability, to suppress malodors, and to facilitate storage, transport, and application to land. Organic recycling allowed farmers to maximize their crop production with negligible soil erosion and nutrient runoff.

Agriculture in the Near East

For about 5000 years after farming began in the Near East, the early farmers planted seeds by dibbling, that is, by placing seeds in holes made with a pointed stick. This practice still exists among primitive peoples in remote regions. With the invention of the plow in the Near East (3000 - 2500 B.C.), agriculture began to develop rapidly since more land could be cultivated. According to MacKay (1950), by 2000 B.C. agriculture in the Near East had become relatively advanced in the production of livestock and the growing of cereals, vegetables, and tree crops. These farmers had learned that animal manures and nitrogen-fixing legumes, including vetches, alfalfa, and peas, could help maintain soil fertility.

Table 1. Milestones in the development and evolution of organized agriculture.[1]

Years	Significant Events
9000 - 8000 BC	Sheep domesticated in Near East.
8000 - 7000	Goats domesticated in Persia. Wheat and barley cultivated in Near East Pattern of village life developed in Near East.
7000 - 6000	Cattle domesticated in Near East.
6000 - 5000	Agriculture replaced hunting in Europe. Corn cultivated in Mexico.
4000 - 3000	Potatoes grown in South America. Rice cultivated in Far East. Farming developed in China, Mexico, and Peru.
3000 - 2500	Plow developed in Near East.
2000 - 1500	Advanced farming developed in Near East.
500 BC - 500 AD	Advanced farming developed under Greeks and Romans. Many farming textbooks written. Fallowing, manuring, composting, and crop rotations advocated. Wheeled plow developed, fitted with moldboard.
500 - 1000	The Dark Ages. Little new knowledge on farming. Few new textbooks written. Roman farming practices continued.
1000 - 1500	The Middle Ages. Increased livestock husbandry. Some development of fallowing, manuring, and crop rotation practices. Primitive moldboard plow developed.
1500 - 1600	Invention of printing press facilitated spread of knowledge on farming. Improved moldboard plow developed.
1600 - 1700	Corn, potatoes, tobacco introduced to Europe from America. Knowledge of chemical agriculture advanced.
1700 - 1800	Mechanization of agriculture advanced.
1862	USDA and Land-Grant University System established.

[1] Compiled from MacKay (1950), Fussell (1965), White (1970), and Leonard (1973).

Greco-Roman agriculture

Agricultural technologies from the Near East were introduced to Greece by Persian invasions beginning about 500 B.C., and additional knowledge was obtained by the Greeks two centuries later from the conquests of Alexander the Great in Babylonia and Egypt (Fussell, 1965; White, 1970). The dispersal of new agricultural crops and technologies reached its zenith during the Roman Empire after their conquests of Greece, the Near East, and much of Europe.

The power and glory of Rome and its empire can be attributed considerably to the stability and productivity of its agricul-

ture. The most prominent Roman agriculturists and technical writers included Cato the Elder (234 - 149 B.C.), Varro (116 - 27 B.C.), Columella (ca. 25 A.D.), Pliny the Elder (23 - 79 A.D.) and Palladius (ca. 450 A.D.). All these authorities made major contributions to the art and science of practical farming, and emphasized the benefits to agriculture that could be derived from organization, management, and conservation of natural resources, especially soil and water (Fussell, 1965; White, 1970). They were extremely prolific writers who published numerous textbooks on all aspects of agriculture, including animal husbandry, crop husbandry, and soil and water management. Their teachings and writings led to significant advances in mechanization, tillage systems, fallowing, crop rotations, multiple cropping techniques, water conservation, and drainage. They emphasized the importance of maintaining soil fertility through such practices as animal manuring, composting, green manuring, liming and marling, recycling of crop residues, and applying sewage wastes, wood ashes, and seaweed.

After the fall of the Roman Empire, the Dark Ages (500-1000 A.D.) produced little new information on farming, and no new textbooks were written. Farmers continued using the methods and techniques established by the early Roman agriculturists. The Middle Ages (1000 - 1500 A.D.) also contributed very little to the advancement of agricultural science and technology, although there was a shift toward increased livestock husbandry in northern and western Europe, and some improvement in implements. Wars, famine, and disease also were rampant during this period, and certainly contributed to the slow progress (Fussell, 1965). Only after the Renaissance started did agricultural science and technology begin to make significant advances again.

The importance of soil quality

The Soil Science Society of America (1984) has defined soil quality as an inherent attribute of a soil that is inferred from soil characteristics or direct observations. Such characteristics and observations allow some conclusions about a soil's inherent fertility and ability to resist compaction, crusting, and erosion. The term is often used to refer to a soil's relative or potential productivity.

An early reference to the importance of soil quality was attributed to Xenophon, an early Greek philosopher (430 - 355 B.C.), who insisted that successful farming depended on the farmer's intimate knowledge of his land and soil, the quality of which he could judge by the natural ecology. He wrote that if the vegetation was abundant and the soil supported ample growth of wild fruits and weeds, it would produce good crops if it was well tilled and managed (Fussell, 1965). This method of estimating soil quality and classifying the production capability of soils is still used today. The simple terms for classifying soils during the Greco-Roman period were "black", "sandy", "clayey", "dry", and "wet".

In his assessment of how much importance early farmers attached to soil quality, Allison (1973, p. 3) wrote:

> Soil organic matter has over the centuries been considered by many as the elixir of life—in this case of plant life. Ever since the dawn of history, some eight thousand or more years ago, man has appreciated the fact that dark soils, commonly found chiefly in the river valleys and broad level plains, are usually (but not always) productive soils. He also realized at a very early date that color and productivity [of soils] are commonly associated with organic matter derived chiefly from decaying plant materials.

Since the time of Xenophon, the term "soil quality" has been largely (if not exclusively) equated with soil productivity. However, today in the United States the term has taken on a much greater meaning because of the strong sustainable agriculture movement (Reganold et al., 1990).

Thus, while soil productivity is still a part of soil quality, the concept has been broadened to include attributes of environmental quality, human and animal health, and food safety and quality (Parr et al., 1992). Currently, in the U.S. there is great interest in how soil quality can be quantified into indexes that can be used as a tool to characterize the status of soil health, and to serve as early warning indicators of soil degradation and the need for remedial measures (Parr et al., 1992).

Most definitions of sustainable agriculture agree that it is a concept or goal of developing farming systems that over the long term are productive and profitable, environmentally sound, and energy conserving, and that enhance health and safety. Low-input alternative methods and skilled management can contribute significantly to achieving this goal (Parr et al., 1990). The relationship between the goal of sustainable agriculture and the strategy of alternative agriculture is illustrated in Figure 1. Most of the alternative practices cited involve the addition of organic amendments that would improve soil tilth, fertility, and productivity. In a recent paper, Parr et al. (1992) proposed that soil quality provides a vital link between alternative agriculture and sustainable agriculture, and that soil quality is the key to long-term agricultural sustainability.

Soil Erosion—A Major Obstacle to a Permanent Agriculture

In 1938-39, some three decades after F.H. King's historic trip to the Orient, W.C. Lowdermilk, then Assistant Chief of USDA's Soil Conservation Service, traveled to Europe, North Africa and the Near East to study the status of lands that had been cultivated for centuries and even millennia, and to obtain information that could help to solve soil erosion and land use problems in the United States (Lowdermilk, 1953).

He found that many ancient cities and empires of the Fertile Crescent that once had a stable and productive agriculture had become virtual graveyards. Lowdermilk gave several reasons for the decline of these once great civilizations. At first, agriculture was confined mainly to the alluvial plains and valley bottom lands. As populations increased, forests were cut and the poorer quality sloping lands were cultivated intensively. The result was extensive erosion, sedimentation of the Tigris and Euphrates Rivers and tributaries, siltation of irrigation canals, and salinization of poorly drained irrigated lands. Lowdermilk (1953, p. 27) concluded that:

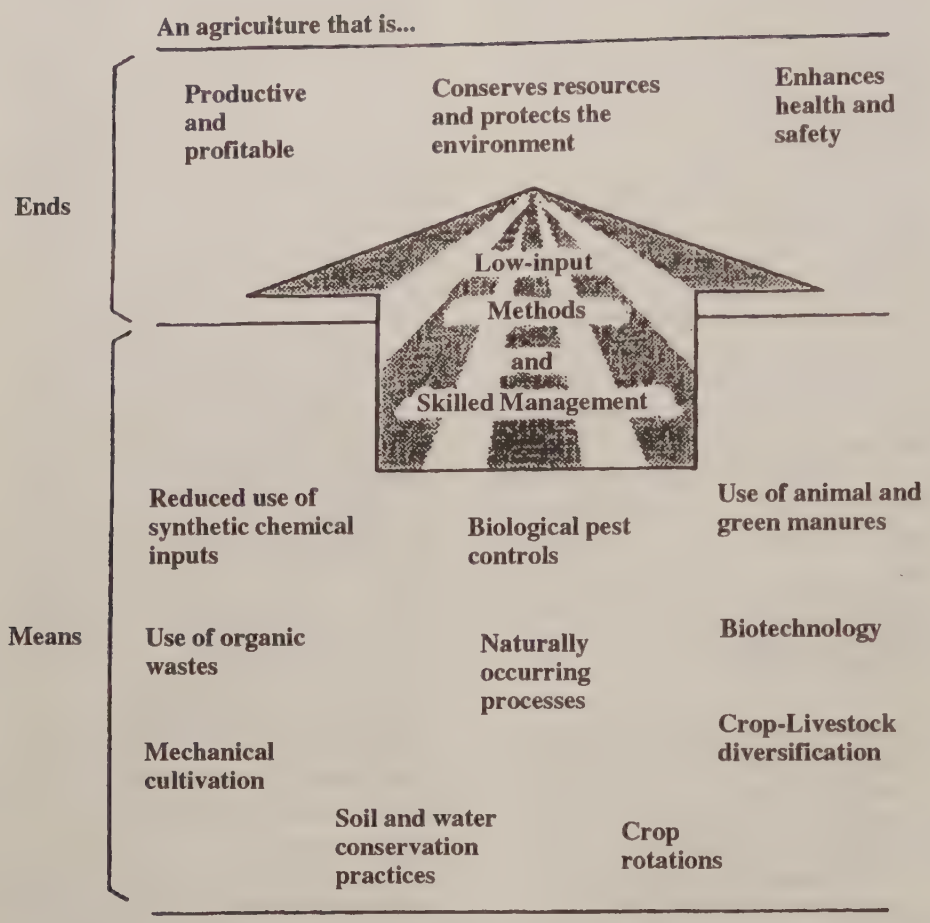

Figure 1. A current concept of sustainable agriculture in the United States showing the ends or objectivs and the means of achieving them through low-input methods and skilled management.

A solution to the problem of farming sloping lands must be found if we are to establish an enduring agriculture in the United States. We have only about 100 million acres of flat alluvial land where the erosion hazard is negligible, out of 460 million acres of land suitable for crops. Most of our production comes from sloping lands where the hazard of soil erosion is ever present. This calls urgently for the discovery, adaptation, and application of measures for conserving our soils.

Meanwhile, more than four decades after Lowdermilk voiced his concerns, soil erosion by wind and water, and the associated loss of soil productivity and soil quality, remains our most serious agricultural and environmental problem. For example, Brown and Wolf (1984) estimated that the worldwide rate of topsoil loss from erosion is about 0.7% per year. In 1982 USDA's Soil Conservation Service estimated that about 2.3 billion tons of topsoil per year was being eroded from U.S. cropland by wind and water (Brosten, 1988). According to Brosten (1988) this is enough soil to fill a freight train of 100-ton hopper cars 241,761 miles long, almost ten times the earth's circumference. Brosten suggests that a major shift from conventional tillage to conservation tillage practices such as no-till, strip tillage, ridge tillage, mulch tillage, and reduced tillage, could significantly reduce soil erosion of our croplands.

These statistics are alarming in view of the extensive research that has been conducted in the U.S. on the mechanics, measurement and control of soil erosion. It is also of concern because most of our agricultural soils have been farmed for less than 150 years, many of which have already lost much, if not most, of their topsoil (Gibbons and Wilson, 1984). Obvious questions then are how and why this has happened. Table 2 lists some reasons that conservation farming methods have not been adopted and practiced by early and more recent farmers. Several of these are discussed in the following section.

Changes in Farming Systems in the United States since 1900

For the first half of this century, most farms in the U.S. were mixed crop-livestock operations. Farmers produced forages and feed grains for their animals through long-term crop rotations that did

Table 2. Reasons that conservation farming methods have not been more widely adopted and practiced over time.

1. Lack of skilled management.
2. Lack of incentives and motivation.
3. Abundance of cheap and available land.
4. Intensive production of cash grain crops to enhance short-term economic gain.
5. Government farm programs have discouraged conservation farming.
6. Shift from mixed crop-livestock operations to high chemical-intensive monoculture cash grain systems.
7. Population pressures have caused increased cultivation of marginal lands.
8. Favorable commodity prices have encouraged cultivation of marginal lands.

not require large input purchases each year. Soil productivity was maintained by crop rotations, including nitrogen-fixing legumes, and the return of crop residues and animal manures to the land. Few pesticides were used. Weeds, insects, and plant diseases were controlled mainly through crop rotations, mechanical cultivation, and biological means, such as natural predators (National Research Council, 1989).

It is ironic that about the same time Lowdermilk (1953) published the findings of his Near East tour and expressed his concern for protecting sloping farmlands in the U.S., farmers in this country began to shift from mixed crop-livestock operations to highly specialized cash grain monocultures. Monoculture, or the practice of growing the same crop on the same land through at least two crop cycles, is most important in the U.S. for wheat, corn, soybeans, cotton, sorghum, and tobacco. The three main factors that propelled U.S. farmers toward monoculture were advanced large-scale mechanization, improved crop varieties, and the availability of low-cost chemical fertilizers and pesticides (Power and Follett, 1987). These enabled farmers to shift from crop rotations and animal related enterprises to monoculture cash grain crops, which significantly increased their net return. Other advantages of monoculture are more efficient use of machinery, lower labor costs, and simplified marketing (Power and Follett, 1987).

Government programs and farm subsidies greatly reduced the risk of specialization. However, they also encouraged the separation of feed grain production from the livestock component, which was rapidly transformed into a feedlot industry. This resulted in the decline of two vital soil and water conservation practices: the return of animal manures to the land, and the rotation of grain crops with grasses and legumes. Consequently, farmers who specialized in cash grain production had to increase their inputs of chemical fertilizers and pesticides to compensate for the lost benefits of crop rotations.

Thus, for the last four decades U.S. agriculture has substituted machinery, pesticides, chemical fertilizers, irrigation, and energy in place of crop and livestock diversity, labor, land, and traditional farm management. This, in turn, has led to many of the current problems associated with U.S. agriculture, including excessive soil erosion, loss of soil productivity, pollution of surface and groundwater by sediment and agrichemicals, health risks and environmental impacts of pesticides, and food safety and quality. It has also raised questions concerning the long-term sustainability of our farming systems.

Soil Organic Matter: Its Role and Value in Crop Production

A very comprehensive treatment of the role of organic matter on soil productivity and crop production is that of Allison (1973). Even a cursory reading of this book leaves no doubt that the key to soil fertility and productivity is soil organic matter from proper and regular additions of organic amendments. A summary of the beneficial effects of soil organic matter on soil properties is shown in Table 3. All the effects shown, including nutritional, chemical, physical, and biological, extend over time. For example, certain plant nutrients such as nitrogen, phosphorus and sulfur contained in organic materials are in organic forms and not available to plants until these materials are decomposed by soil microorganisms. The soil chemical and physical properties also are enhanced as decomposition proceeds. For example, as soil microorganisms use organic wastes or crop residues as a carbon source, they produce polysaccharides that can bind soil particles together into stable aggregates, thereby improving tilth and reducing soil erosion.

Table 3. Beneficial effects of soil organic matter on soil properties (Allison, 1973).

Soil Property Affected	Beneficial Effect
Nutritional	
Micronutrients	Provides Cu, Mn, Zn, B, Cl, Mo
Macronutrients	Provides O, H, C, N, P, S, Fe, Ca, Mg
Chemical	
Cation exchange capacity	Increases
Buffering capacity	Increases
Chelating capacity	Increases
pH	Alleviates acidic and alkaline conditions
Physical	
Soil aggregation	Increases
Aggregate stability	Increases
Water holding capacity	Increases
Soil porosity	Increases
Water infiltration	Increases
Water percolation	Increases
Soil crusting	Decreases
Bulk density	Decreases
Biological	
Beneficial microorganisms	Produces polysaccharides/antibiotics
	Increases nutrient availability
	Suppresses plant pathogens
	Decomposes organic wastes
Earthworms	Populations increase

The application of organic materials to soils also increases the efficiency of chemical fertilizers. For example, a 50-year study (1890-1940) at Sanborn Field, Columbia, Missouri, showed that a combination of animal manure and chemical N fertilizer resulted in higher yields of corn, wheat, and hay, and higher N-use efficiency, than from either N source applied alone (Smith, 1942).

The true value of organic materials as biofertilizers and soil conditioners is often misunderstood (Parr and Colacicco, 1987). The simplest and most common way to estimate the value of organic materials is to consider them as partial substitutes for chemical fertilizers that would otherwise have to be purchased. This is done by assessing the current market value of the plant nutrients they contain, especially the macronutrients (nitrogen, phosphorus, and potassium). Many organic materials contain other macronutrients and micronutrients that can contribute significantly to higher crop yields (Table 3). When any of these nutrients substitute for essential production inputs, the value of a particular organic material increases accordingly. An additional benefit of many organic materials is that they have a greater residual effect on soil fertility than most chemical fertilizers because they release N and P slowly. Thus, a significant portion of the true value of organic materials is their ability to increase the yield of succeeding crops (Parr and Colacicco, 1987).

The Dynamics of Soil Productivity

An important relationship often overlooked with agricultural soils is illustrated in Figure 2. Usually, degradative processes such as soil erosion, losses of nutrients by runoff, and organic matter depletion occur simultaneously with the beneficial effects of conservation practices such as crop rotations, conservation tillage, and recycling of animal manures and crop residues (Hornick and Parr, 1987). As soil degradative processes intensify, soil productivity decreases concomitantly. Conversely, soil conservation practices tend to slow these degradative processes and increase soil productivity. Thus, the potential productivity of a particular soil is the result of ongoing degradative processes and applied conservation practices. Generally, the most serious degradative processes are soil erosion and associated depletion of plant nutrients and organic matter.

On our best agricultural soils—that is, gently sloping, medium-textured, well-structured soils with a deep, well-drained profile—a high level of productivity can be maintained by a few essential conservation practices that readily offset most degradative processes. However, soil conservation practices must be maximized to counteract further degradation on marginal soils of limited capability, such as steeply sloping, coarse-textured, poorly-structured soils that are depleted of nutrients and have a shallow, poorly-drained profile. Thus, a truly sustainable farming system is one in which the beneficial effects of various conservation practices equal or exceed the harmful effects of degradative processes. Organic wastes and residues offer the best way to restore the productivity of severely eroded agricultural soils or to reclaim marginal soils (Hornick and Parr, 1987).

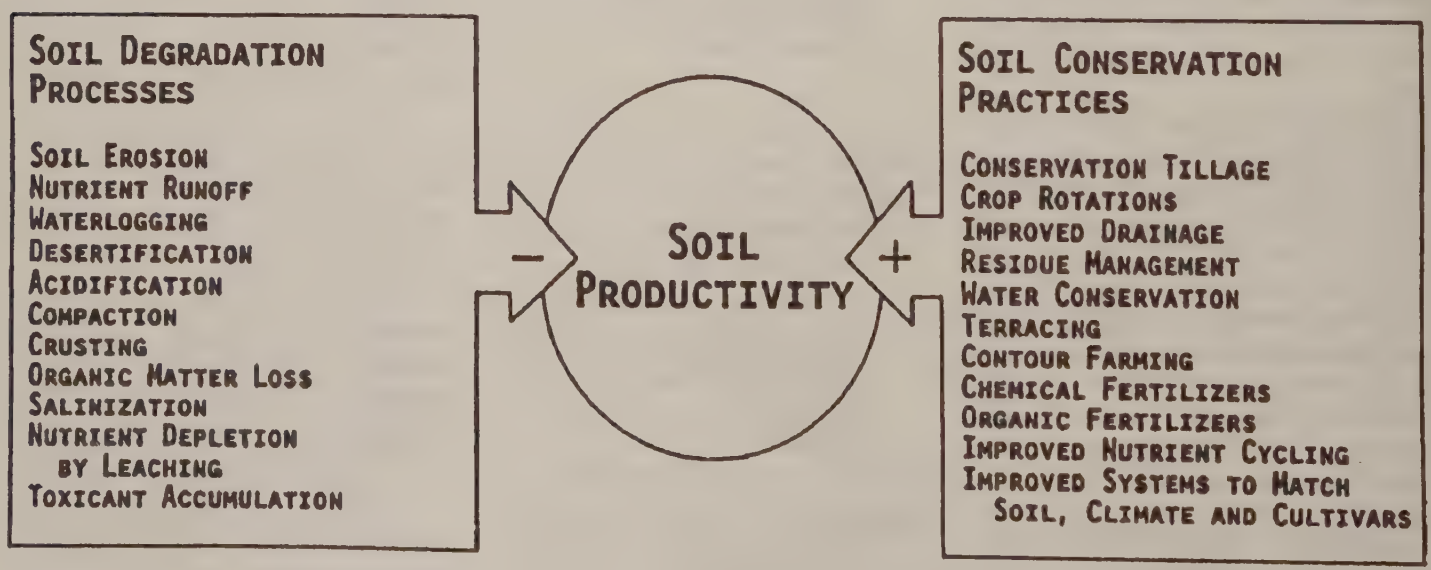

Figure 2. Soil productivity is the result of interactions between soil degradative processes and soil conservation practices (Hornick and Parr, 1987).

Use of Municipal Wastes as Soil Conditioners and Biofertilizers

The two principal waste streams that have emerged with municipal development are sewage sludge and effluents, and solid waste or garbage. For centuries municipal wastes have been used as soil conditioners and biofertilizers to enhance the productivity of agricultural lands. During the last two decades, considerable research has been conducted to ensure that sewage sludges could be used safely and beneficially on cropland (U.S. Environmental Protection Agency, 1989a; Chaney, 1990a,b).

Composting has received considerable attention as an effective way to transform raw, unstable municipal wastes into acceptable and valuable soil amendments. For example, in the early 1970s USDA scientists with the Agricultural Research Service at Beltsville, Maryland, developed a process for rapid composting of sewage sludges that has been adopted by many U.S. cities and municipalities, in place of ultimate disposal methods such as incineration, landfilling, and ocean dumping (Willson et al., 1980; Hornick et al., 1984). More than 30% of the sewage sludge produced in the U.S. is now being used beneficially on agricultural and nonagricultural land as compost, or by land spreading and liquid injection (U.S. Environmental Protection Agency, 1990a).

A major problem in the U.S. and many other countries is how to manage our municipal solid waste (MSW) in view of the increasingly restrictive environmental regulations against ultimate disposal methods (Parr and Hornick, 1992). Only about 10% of our MSW currently is recycled, while 10% is incinerated and 80% is landfilled. The situation is critical for many cities and municipalities because landfills are filling up, and the development of new landfills is environmentally objectionable and extremely expensive. A substantial reduction in both the number and remaining capacity of U.S. landfills is projected for the year 2000 (Parr and Hornick, 1992). The current annual U.S. production of MSW is about 165 million dry metric tons, or a per capita annual production of about 600 kg (U.S. Environmental Protection Agency, 1989b). The estimated production of MSW will increase to about 200 million tons by the year 2000 and to 230 million tons by 2010 (U.S. Environmental Protection Agency, 1990b).

The kind and amount of materials that comprise the nation's MSW stream are shown in Table 4. The largest single component is paper and cardboard products, which accounts for 35%, followed by yard waste (grass clippings, leaves, and trimmings from trees and shrubs) at about 20%. These two waste fractions combined with food waste (8.5%) and discarded wood products (4.2%) account for approximately two-thirds of our MSW, most of which goes into landfills. All four of these waste materials are biodegradable and could be composted or cocomposted for beneficial use as soil conditioners and biofertilizers on agricultural and nonagricultural lands. Metals, glass, and plastics comprise about 25% of our MSW and have considerable recyclable value, especially when municipalities introduce source separation or curbside collection programs.

Table 4. Percent composition of materials by weight in U.S. municipal solid waste (U.S. Environmental Protection Agency, 1990b).

Material	Composition (%)
Paper and cardboard	34.2
Yard waste	19.9
Food waste	8.5
Metals	8.1
Glass	7.1
Plastics	9.2
Wood	4.2
Rubber and leather	2.9
Textiles	2.5
Other	3.4

Recent Legislation Concerning the Agricultural Use of Residuals

There have been several recent legislative initiatives by the U.S. Congress that are relevant to agricultural use of rural and urban wastes for improving the productivity, quality, and sustainability of our soils.

The Food and Agriculture Act of 1977 (PL 95-113)

This Act, also known as the 1977 Farm Bill, required that USDA submit a report to the Congress on "the practicability, desirability, and feasibility of collecting, transporting, and placing of organic wastes on land to improve soil tilth and fertility." This is the first known official request for an inventory of organic waste production in the U.S. Information was requested on the kinds, amounts, and availability of organic materials that could be used as soil conditioners and biofertilizers for improving soil productivity and counteracting excessive soil erosion. A summary of the USDA Report is shown in Table 5 (U.S. Dept. of Agriculture, 1978). The total annual production of both rural and urban wastes in 1977 was approximately 730 million dry metric tons. More than 90% of the total amount consists of crop residues (53.7%), animal manures (21.8%) and municipal solid waste (18.1%). Crop residues and animal manures already are being recycled on land to a much greater extent than other wastes, and are not likely to become significantly more available. Since these data were compiled, the amount of sewage sludge applied to land has increased from about 23% to more than 30%. MSW offers the greatest potential for increased agricultural use as soil conditioners and biofertilizers.

The USDA Report concluded that these wastes represent a national resource of significant economic value, and that there is a growing shortage of good quality organic wastes for use in maintaining and improving the productivity of our agricultural soils.

The Food Security Act and Agricultural Productivity Act of 1985 (PL 99-198)

These Acts made up the 1985 Farm Bill, which provided for the Conservation Reserve Program (CRP) that was implemented in 1986. The CRP called for the removal of up to 45 million acres of highly

Table 5. Annual U.S. production of organic wastes in 1978 and amounts that were recycled on land (U.S. Dept. of Agriculture, 1978).

Category of Organic Waste	Total Production		Amount Recycled on land
	10^6 Dry Metric Tons	% of Total	
Crop Residues	391	53.7	68
Animal Manures	159	21.8	90
Municipal Solid Waste	132	18.1	1
Logging/Wood Products	32	4.5	5
Industrial Organic	7.5	1.0	3
Sewage Sludge	4.0	0.5	23
Food Processing	2.9	0.4	13
TOTAL	728.4	100.0	

erodible U.S. cropland from agricultural production. Land that is assigned to the CRP is under a 10-year bond with USDA, during which time the landowner receives annual payments for either planting trees or seeding the land to grasses and maintaining a continuous cover. The original intent of CRP was to retire a large amount of these fragile lands from crop production permanently. However, a substantial amount could return to cropland as early as 1995. If they are cropped again, the best way to protect them against further degradation by wind and water erosion is proper and regular additions of organic amendments. Moreover, since some of these lands will not produce sufficient amounts of crop residues to control erosion, the most feasible way to protect them may be to use urban or other off-farm wastes.

The 1985 Farm Bill also authorized the USDA to conduct research and education programs on alternative agriculture, or more specifically on low-input or sustainable farming systems (U.S. Dept. of Agriculture, 1988). The concept that has emerged is one of low-input/sustainable agriculture or LISA, which has contributed to the adoption of management practices by farmers that enhance the production and use of organic amendments (e.g., crop residues, green manures, and animal manures) that can improve soil productivity and the sustainability of farming systems.

Food, Agriculture, Conservation, and Trade Act of 1990 (PL 101-624)

This Act, also known as the 1990 Farm Bill, provides for a National Composting Research and Extension Program (Section 1456). Specifically, it requires USDA to "compile information on appropriate methods of composting agricultural wastes from the production, processing, and distribution of food, fiber, forestry, and fish products, and the potential use of such compost." It further directs USDA to:

> Conduct research on the potential uses for compost derived from animal wastes, and from other waste streams as appropriate, and identify uses for such compost, including the potential for marketing such product. Such research shall also include evaluation of the application of compost derived from agricultural wastes on soil, plants, and food and fiber crops.

These initiatives show the concern that environmentalists, farmers, consumers, conservationists, and the public have for maintaining and restoring the productivity of our agricultural lands. Emphasis on recycling and processing of selected organic wastes from the rural/urban interface for safe and beneficial use on land is likely to increase considerably in the future.

Summary and Conclusions

Most "best management practices" that we recommend to today's farmers to enhance the productivity of their croplands were developed by farmers many centuries ago. Greek and Roman agriculturists wrote extensively of the benefits of crop rotations, fallowing, mulching, multiple cropping, animal manuring, green manuring, composting of organic wastes, and liming. The value of recycling organic wastes and residuals from both rural and urban sources became widely recognized as the best way to maintain and improve the tilth, fertility, and productivity of agricultural lands. Today, soil organic matter still remains as the undisputed key to soil productivity. Through the centuries, farmers often have neglected or even abandoned the practice of recycling organic residuals when they switched to intensive tillage and monoculture systems to increase production and profitability. They have always paid dearly for this neglect, because it has led to excessive soil erosion, depletion of soil fertility, nutrient runoff, and loss of soil organic matter, all of which have culminated in the often irreparable loss of soil productivity.

In the United States, soil erosion by wind and water, and the associated loss of soil productivity and impairment of soil quality, remain our most serious agricultural and environmental problems. Although soils in some parts of the world have been cultivated and conserved for more than forty centuries, most U.S. agricultural soils have been farmed for less than 150 years. Unfortunately, because of poor farming practices, many of them have been highly eroded, losing much of their topsoil and potential productivity.

Recent federal legislation has called for action programs to encourage the proper and regular addition of rural and urban wastes, and their safe and beneficial use, for improving the productivity, quality, and sustainability of our agricultural lands. National inventories of the kinds, amounts, and availability of organic materials that could be used as soil conditioners and biofertilizers should be conducted and updated every five years. A National Composting Research and Extension Program that was called for in the 1990 Farm Bill

could go a long way toward providing valuable organic materials for maintaining and restoring the tilth and fertility of our soils. Practical and reliable on-farm composting methods will be needed to ensure the success of this program. Highly erodible croplands that are currently under the Conservation Reserve Program would also benefit from the proper and regular application of composts or other amendments when these lands are returned to crop production.

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COMMENTARY

What will be required to guarantee the sustainability of U.S. agriculture in the 21st century?

Michael R. Dicks

Abstract. *The increased effort by Congress to reduce agriculture's adverse consequences on the environment has been focused almost entirely on changing agricultural production practices at the farm level. Because the agricultural sector is highly integrated, attempts to change a specific industry within the sector, such as production, input supply, or processing, may have undesirable effects. Programs designed to achieve society's environmental objectives by forcing change in agricultural production practices will lead to increased frustration, new programs and regulations, and further conflict between society and farmers. To guarantee sustainability of U.S. agriculture into the next century, efforts to incorporate new social needs into production agriculture should include changes in the research agendas of public and private institutions, marketing grades and standards, and the institutions that support the agricultural producer.*

Key words: sustainable agriculture, food security, property rights, environmental regulations, weed science

Introduction: Changing Environmental Concerns

Federal and state legislative efforts to clean up the environment began in earnest during the 1960s, when large, single or "point" sources of highly visible pollution were targeted. The targeting of smaller point sources such as municipal sewage treatment facilities followed. By the 1980s, the target became diffuse or "non-point" sources of pollution, such as agriculture and construction. The most diffuse source of pollution and the last to be dealt with will inevitably be the individual consumer.

The movement from large point sources to diffuse non-point sources was not arbitrary. The cost of enforcement and monitoring per unit of pollution abatement was much smaller for point sources than for non-point sources, while the benefits were considerably larger. In addition, scientific knowledge and public awareness of the sources and processes of environmental degradation have grown rapidly in recent years, uncovering previously unseen forms of environmental damage, such as groundwater contamination.

The ability to measure and monitor environmental conditions has led to increased awareness of environmental problems such as ozone depletion and groundwater contamination. However, the complexity of the systems being measured has complicated the task of identifying specific causes and solutions to problems. Because of the lag between society's awareness of environmental problems and science's ability to mitigate the problems, Congress often is forced to legislate solutions that err on the side of human safety. Thus, pressure will persist for agriculture to incorporate environmental concerns into every aspect of current agribusiness practices.

The environmental concerns voiced during the debates on environmental legislation throughout the 1980s could be condensed into one unifying theme: sustainability. The debate is largely influenced by differences in how this concept is defined. In the section that follows, I provide several widely used definitions of sustainability, along with a summary definition that incorporates the common characteristics of each. The next section discusses two issues (the target group and property rights) that are directly affected by how sustainability is defined. The final section identifies several factors contributing to the development of current agricultural production practices that must be changed to guarantee the future sustainability of agriculture.

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What is Sustainability?

Webster's *New World Dictionary* defines sustainability as the ability to keep in existence, maintain or prolong. Pearce (1989) maintains that sustainability is about being fair to the future, leaving the next generation a similar or better resource endowment. Ikerd (1991), representing the sustainable agriculture movement, argues that agricultural sustainability means keeping farms both ecologically sound and economically viable.

From a broader perspective, Pearce and Turner (1990) argue that a sustainable system must follow four basic rules:

- Use renewable resources at a rate less than the natural rate of regeneration.
- Maintain wastes from production below the assimilative capacity of the environment.
- Ensure that the reduction of nonrenewable resources is compensated for by increases in renewable resources.
- Guarantee that depletion of nonrenewable resources occurs only if accompanied by an increased standard of living.

Still other authors denote sustainability with words such as ecological agriculture and permaculture—the conscious design and maintenance of economical, agriculturally productive ecosystems that have the diversity, stability and resilience of natural ecosystems (Mollison, 1990).

Another approach is to describe the characteristics of a sustainable farm (Doering, 1991). Sustainability in farming implies:

- less specialized farming and more mixed crop/livestock farming with less dependence on off-farm inputs;
- full pricing of off-farm inputs, with no price supports for crops that degrade the environment;
- producers bearing the costs of off-farm environmental damage;
- family sized farms rather than corporate factory farms.

Doering summarizes these characteristics of sustainability as implying "a structurally different system from today's."

The Senate defined Low-Input Sustainable Agriculture (LISA) as a system "that, for generations to come, will be not only productive and profitable but will conserve resources, protect the environment, and enhance the health and safety of the citizenry" (U.S. Senate, 1990). The Senate Committee on Agriculture, Nutrition and Forestry notes that the term "low-input" was added by the Department of Agriculture "to give more meaning to the rather general concept of sustainability." The Senate definition for LISA fits well with the broader concept defined by Pearce and Turner (1990). To "conserve resources" implies use at a rate that does not exceed the natural rate of regeneration. "Protect the environment" implies maintaining the level of contaminants at or below the assimilative capacity of the environment. To "enhance the health and safety of the citizenry" implies permission to use nonrenewable resources such as petroleum-based chemicals to increase the standard of living.

These and many similar definitions show the depth and breadth of the concept of sustainability. The wide variation allows various groups to develop a definition that advances their beliefs. For example, the extreme environmental groups might use the dictionary and Pearce definitions to argue that resource endowments must be preserved for future generations without exception. These groups may define resource endowments as pristine natural resources, such as wildlife and rivers. Therefore, being fair to the future means that the pristine natural resources should be left as they are, unfettered by man. Since the extreme groups view all chemical applications as threatening to pristine natural resources, sustainability would be contingent on the elimination of all agrichemicals.

The common thread of all the definitions is the requirement that future generations have access to the same or better quality and quantity of food, fiber and environmental amenities as we have today. To achieve this, the agriculture-environment debate should focus on whether the current structure of the agriculture sector will foster future resource endowments equal to today's. This does not imply that the quantity and quality of the current set of natural resources must remain unchanged, but that the standard of living achievable with the current set of capital, human and natural resources must at minimum be unchanged in the future.

Why is the Sustainability Concept Important?

How sustainability is defined will determine who is the target of change. More important, the change will be both limited and affected by property rights. The experience of other countries shows that sustainability is defined primarily according to social objectives and the resources available to achieve them. The U.S. experience over the past quarter century shows how quickly social objectives can change. The change in the United States has been toward greater protection of the environment. In agriculture, the emphasis on environmental protection has been targeted to changes in agricultural production practices. The effects have been limited, leading to frustration and increased conflict between society and agricultural producers.

Because of our natural material wealth and effective economy, the United States has been spared the choices made in the Soviet Union and in many Third World countries between poverty on the one hand and environmental destruction on the other (McGuire, 1991). In Third World countries where shortages of food and energy are common, environmental destruction is ubiquitous, and sustainability means meeting food needs. The United States currently has the luxury of taking sustainability to mean minimizing environmental degradation while maintaining abundant and relatively safe food supplies. This is quite a change from just two decades ago, when major concerns persisted about our ability to sustain the growth in food production needed to meet the growing world demand.

The abundance of food in the U.S. has helped shape our current concept of sustainability. This should not be taken lightly: the current focus of the agriculture-environment debate is a direct result of the change in how society views sustainability. With record food surpluses in the 1980s, the emphasis has shifted from food security to concern about potential environmental

calamities. Within a decade, society has changed its perception about the relative severity of two persistent agricultural problems: food scarcity and environmental disturbance. For instance, Offutt (1989) notes that because agriculture, by its very nature, disturbs the natural environment, "the real issue is how much disturbance society will accept: not whether it will accept any at all." This statement mirrors society's current movement toward defining sustainability with the objective of minimizing environmental disturbance rather than maximizing food production with limited environmental disturbance. Although there is abundant information about the effects of agriculture on specific natural resources such as soil, land, and water, exact measures of the environmental disturbances caused by agriculture are scarce. Society is repeatedly told that production agriculture disturbs the environment, yielding a net cost to society. Yet some agricultural activities provide net benefits to society even though environmental disturbances are necessary to do so.

Clearly, environmental disturbances are to be minimized under the new concept of sustainability. The question then becomes what segment of agriculture will be the target of activities to reduce disturbances. In a recent article, Representative George Brown (D-Calif.) commented that

> All sectors of the agricultural community need to face up to a number of basic realities. First, the pressures will increase as the public demands that more emphasis be placed on environmental quality. Second, there are legitimate concerns about the health and environmental effects of agricultural chemical use. Our past assumptions are being proved incorrect with each discovery of a chemical in groundwater. Third, the farm and rural sector has a lot to gain or lose in the environmental debates and must now become a part of them. (Brown, 1989, p.16)

Faeth et al. (1991, p. 16) take Brown's statement one step further by identifying the target group and the method of action:

> In theory, U.S. agriculture is a business enterprise like any other, so any decline of capital assets should figure in income calculations. In practice, however, farmers depreciate man-made assets such as tractors or silos, but make no allowance for the declining value of natural assets such as soil and water. To the extent that U.S. farmers are living off their capital by allowing soils to erode and water to be contaminated, their income is overstated today—and at risk tomorrow.

Again, in a recent article addressing water quality, Carriker and Purvis (1990, p. 27) lament that

> the public's growing concern about agriculture and water quality has been accompanied by an increasingly negative view of agriculture and the land grant colleges. Farmers are being admonished by people of substantial political influence to take responsibility for agricultural impacts on the environment.

Many more examples could be provided, all of which imply that the cost of implementing society's concept of sustainability will be borne by the whole agriculture sector, but more specifically by farmers. In addition, the recent ruling of the U.S. Supreme Court in Wisconsin Public Intervenor et al. vs. Ralph Mortier et al., to the effect that local ordinances banning or limiting the use of pesticides are not preempted by Federal pesticide regulations, opens the door to defining sustainability as a local rather than a national concept. Thus, a national policy on sustainability may become moot if agricultural producers are forced to meet a more restrictive local definition. Under this scenario, any competitive advantage in agricultural production found in a particular local jurisdiction may be offset by changes in how that locality perceives sustainability. For example, it might set more stringent pesticide standards than are contained in the Federal Insecticide, Fungicide and Rodenticide Act. Also, our competitive position internationally will depend in part on our competitors' perception of sustainability and their implementation policies. The result is that the agricultural producer, not the complex of agricultural institutions forming the U.S. agriculture sector, is currently the focal point for implementing the new concept of sustainability, that is, minimizing environmental disturbances.

Sustainability and Property Rights

The ability to change farmer behavior through regulation will be limited in the short run by the current structure of property rights. However, in the longer run, the changing definition of sustainability will continue to affect property rights. Property rights are defined in terms of the initial ownership (allocation) of rights and the rules under which they may be exchanged (Braden, 1982). Agriculture has always enjoyed fee simple ownership of land and access to entitlements. The allocation of rights to farmers early in American history represented a "social contract" between agriculture and society. The contract reflected society's belief that farmers could best evaluate the appropriate allocation of farm resources and could act most cheaply to correct errors in an initial allocation. Later, the social contract of the post-1930s included an agreement to protect farmers from income instability. This protection, in the form of entitlements (program benefits) became institutionalized and translated into property rights by farmers (Batie, 1990).

The rules under which property rights may be exchanged can be summarized under three options: property rules, liability rules, and inalienability (Calabresi and Melamed, 1972). With property rules, consent to an exchange of rights must be given in advance by all parties at an acceptable price, like market transactions. Under liability rules, prior consent to an exchange is not required, and prices are set by an objective third party. With inalienability, the exchange of rights is disallowed under some or all circumstances.

The Food Security Act of 1985 (FSA85) introduced a subtle change in property rights. Before the FSA85, the exchange of property rights in agriculture was conducted under property rules. Voluntary soil conservation programs provided cost sharing for farmers to reduce soil erosion. Thus, the right of the farmer to lose soil was

implied, and the price of exchange was negotiated through cost sharing and technical assistance. The FSA85 Conservation Title used liability rules rather than property rules to minimize environmental disturbances. Congress placed specific requirements on how highly erodible land and wetlands are managed. The price for failing to comply was the loss of all commodity program benefits. The Food, Agriculture, Conservation and Trade Act of 1990 (FACTA90) further shifted the rules of exchange. The wetlands provision was changed to revoke commodity program benefits whenever wetlands are altered, not just when an agricultural commodity is produced on altered wetlands. Although strictly speaking, this may not be a move from liability rules to inalienability rules because of the nature of the penalty (loss of commodity program benefits), it comes close. However, under the new meaning applied to Section 404 of the Water Quality Act, Congress provided the Federal government with the right to control any alterations or pollution in wetlands, invoking inalienability as the rule of exchange.

In just five years (between the FSA85 and FACTA90), the rules governing the exchange of rights has shifted from property rules to liability rules for most agricultural property, including land and soil. For others, such as wetlands, the shift has been far more significant, from property rules to inalienability. The new rules governing exchange of property rights can be viewed as new conditions placed on the social contract with farmers. Although these are not the first conditions placed on this contract, they are the first to reduce the direct benefits of the contract to farmers.

The reduction in benefits to farmers through their contract with society also has occurred through society's increasing reluctance to pay to maintain the public goods received from farmers and the agriculture sector as a whole. Food security, like national security, can be considered a public good. Our abundant agriculture is the result of large public expenditures on research and extension, and our past willingness to pay for excess capacity in the sector. The most recent examples of the reluctance to continue to pay for these public goods are the reduction in federal and state funding for agricultural research, the attempts by Representatives Armey (R-Calif.) and Schumer (D-N.Y.) to reduce or eliminate deficiency payments during the 1990 farm bill debate, and actual reductions in the Budget Reconciliation Act of 1990.

In summary, implementation of society's concept of sustainability has focused on agricultural production, rather than the entire agriculture sector. The targeting of farmers has led to a subtle shift in property rights, placing a wedge in the "social contract." This wedge, which continues to grow, may preclude the transformation of agriculture needed to achieve a new sustainability.

How Did We Get Here?

Agricultural producers respond to market incentives in deciding which technologies to use. Production decisions are based on estimated profitability and other factors, such as available capital, available information (and its source), and ease of incorporating a new technology into the current operation. The current structure and resource allocation within agriculture can partially be explained by the relative prices of inputs, by conventional paradigms in our agricultural institutions, and by the social goal of guaranteeing the American consumer a cheap and ample supply of food (food security).

Relative prices of inputs

The prices of chemical nutrients and pesticides have been very low relative to land, labor and machinery over the last four decades. Not too surprisingly, therefore, the use of agrichemicals has grown enormously during this period, while use of land, labor and machinery has declined or remained roughly constant (Doering, 1991). Agricultural research during this period focused on developing crop varieties that use the cheap agrichemical inputs most effectively. The relatively low cost of farm machinery in the first three decades of the post war period reduced the need for crops to support draft animals. With commodity prices declining relative to production costs, farmers strove to increase output to maintain farm income. Low relative prices for agrichemicals, less farm livestock, and the need to expand output combined to move agriculture toward larger farms with intensive monocultures of food and feed grain crops. The agriculture research institutions and public policies provided considerable support for this shift.

Conventional paradigms

The research paradigms that developed over the past 40 years have seriously inhibited change in agricultural production systems. Carriker and Purvis (1990, p. 29) use Dundon's (1982) example of weed research to illustrate the typical research paradigm. Dundon introduced the concept of rival paradigms as an obstacle to creativity within a paradigm and an inhibitor of communication between disciples with different paradigms. He elaborated this idea using the example of the effect of the discovery of the herbicide 2,4-D on weed control research:

> In 1944 two USDA scientists discovered that 2,4-D could kill 98 percent of the clover in golf turf, leaving the turf undamaged. In 1943 (the year before their discovery) there were only 49 citations under weed in the USDA Bibliography of Agriculture. By 1949 there were 600. The weed science establishment had begun to flourish. It focused its efforts on elaborating the success of 2,4-D. Many new compounds and much fine tuning of herbicides ensued.

A weed science paradigm based on chemical treatment was established, and has been maintained until today. When the discovery of a method provides a clear solution to a specific problem, it usually receives great support, and research and development proceeds along those lines. Research within such a paradigm is "dynamic, directed, and, due to past success, colored with optimism and usually backed with administrative support and highly rewarding to the individual scientist" (Dundon, 1982, p. 860). However, other approaches, not proven successful so quickly, are viewed as riskier, are less favored by administrators, and provide less individual reward. Therefore they tend to be shunned by the research establishment.

A similar paradigm exists in developing and delivering agricultural policy. Agricultural policies of today are the same as those of the past, with minor alterations at best. The goals of past policies were to support farm income and provide sustained growth in output. Our social goals have changed and are now being set with new knowledge about environmental quality. The use of traditional agricultural policy instruments to achieve both past (farm income) and present (environmental) goals results in considerable trade-off and compromise. Furthermore, the institutions responsible for setting and administering environmental and agricultural policy were mostly established to carry out past policies. This constrains the opportunity to use new instruments to achieve the new goals of improved environmental quality (Batie, 1990).

Food security

These paradigms, entrenched in the agricultural sector, were born from the need to obtain food security through rapid expansion of output by using lowest priced inputs. Methods once thought successful, reinforced for nearly sixty years, are being scrutinized in light of new information. The old paradigms now confront the new paradigms that have minimizing environmental disturbances as a primary goal.

The excess capacity in agricultural production was born out of our pursuit of food security, the availability of cheap inputs, and large public expenditures for research and development of high yielding varieties able to use the cheap inputs. This excess capacity has provided the flexibility to pursue a change in production technology.

Agricultural producers respond to consumer demands by using the best available technologies and information. Consumer demands have changed to include food safety and environmental concerns besides a cheap and ample supply of high quality, visually appealing food. However, the agricultural research institutions have not changed their research strategies, and processing and marketing firms have been slow to change grades and standards to meet these new consumer demands. Funding sources continue to support the traditional research paradigms. Traditional grades and standards continue to emphasize visual quality.

How Can Agricultural Sustainability Be Assured?

Maintaining agricultural sustainability into the next century will require agriculturalists to be more willing to incorporate new environmental concerns into their concept of sustainability, and to communicate this desire to the public. The environmental groups are neither always right nor always wrong. When research, production, or processing systems disturb the environment more than social goals allow, the implicated institutions need to admit it, change direction, and move on. Continued conflict in face of the facts will harden taxpayers against supporting needed changes in agriculture.

A redistribution of resources is needed within existing research institutions and USDA agencies to provide producers with alternatives that can meet the social goals implied by sustainability. Land-grant institutions have been a cornerstone in developing the technology that has enabled the United States to have a highly efficient agricultural sector. But the traditional paradigms within land-grant institutions have lost touch with the needs (or demands) of the public, the rural population and to some extent the institutions' immediate clientele, namely agricultural producers. For instance, Ikerd (1991, p. 49) described a conventional farming paradigm among southern agriculturalists as the "conventional mind-set regarding the difficulty of producing conventional southern crops by conventional farming methods without conventional pesticides and fertilizer." This accurately captures the real situation confronting farmers. Farmers are under increasing pressure to reduce the use of agrichemicals and conventional tillage practices. But contrary to popular belief, information on alternatives to conventional methods is not readily available to farmers. Current federal programs to increase the efficient use of agrichemicals, for example the Integrated Crop Management Practice and Water Quality Incentives Program, often are regarded as a threat by chemical suppliers, viewed with skepticism by land-grant scientists, and criticized as halfway measures by some environmental groups. However, more significant alternatives are not likely to become available if the conventional farming paradigm continues to control public and private funding.

Continued demands for change without the resources necessary to support development of sustainable production systems will move agriculture closer to the point where one additional event, such as poor weather or a new regulation or restriction, will be the proverbial "straw that breaks the camel's back." Many changes are adding to the collection of straws: a reduced government role in maintaining excess capacity, increasing food safety requirements, grain quality and environmental standards, increased production restrictions, reductions in agricultural research and education, and resistance to change in agricultural institutions.

Over the last decade, production agriculture has come under considerable attack from Congress, environmental and consumer groups, editors of notable daily publications, the general press, and the public. The image perpetuated is of large corporate farms receiving billions of dollars in federal subsidies while wreaking wanton destruction on the environment. Society perceives a strong connection between commodity surpluses and environmental degradation. In fact, most current environmental restrictions in agriculture are targeted at the agricultural producer because of this strong connection. Environmentalists frequently argue that if society is going to support farmers' incomes, it should get something in return. This statement shows society's negative image of excess capacity. Food security is now viewed not as a public good, but as a free good or even a persistent problem, and society has become less willing to maintain it. Thus, current commodity programs that regulate supply through price and income supports are not seen as providing any public good.

The current focus on the agricultural producer rather than the entire agricultural sector may be misguided. The support available from agricultural institutions, such as information, credit, and new technology, affects a producer's ability to change. Because the rate or type of change is not in line with society's perception of

what ought to occur, producers continue to face new regulations. Conservation compliance is just one example. Farmers were given five years to comply, that is, to have a conservation plan implemented. However, this goal has not been reached. Some farmers have failed to comply because of a lack of sound advice, but others simply have refused. Whatever their reasons, a legislative effort has been launched to increase the penalty for noncompliance. Forcing farmers to carry out conservation plans that are economically inferior to current practices—or, even worse, that are infeasible—will erode farm income, and in severe cases reduce agricultural production. Reduction in agricultural output will increase the wedge in the social contract. This is evident in recent trends in funding land-grant institutions. The Morrill Act of 1862 set up the land grant colleges "to promote a sound and prosperous agriculture and rural life as indispensable to . . . national prosperity and security." State and federal funding for these institutions has been declining for the past decade; the emphasis on farming and ranching has been dwindling as the perceived importance of agriculture continues to decline. Producers will be limited in their ability to change without the support of the agricultural institutions. Thus, unless agricultural producers discover new, more environmentally benign production systems on their own, efforts to achieve the new social objectives through regulations are not likely to produce a future agriculture sector with farms that are ecologically sound and economically viable. More to the point, the current relative prices of factors of production, the focus of research and extension, and recent agricultural policies do not support a shift from current agricultural production systems to those that would meet current social objectives. Without changing these conditions, forcing farmers to be more ecologically sound may force them to be less economically viable.

Summary

"Sustainable agriculture" is not a novel concept, but rather the means by which American farmers have continuously operated to insure that family farms may be passed down from generation to generation. Farmers continue to adopt the technologies with the best proven record for providing the greatest profitability for both long and short run success of the farm operation. As new information becomes available, farmers adjust their choice of production technologies. What is novel is the inclusion of environmental concerns in the concept, and the method society has chosen to implement the concept.

Agriculture institutions were responsible for considerable changes in the past, but today these institutions seem resistant to change. This resistance has led society to force change through regulation, changes in property rights, and reduced support for the agricultural sector.

Agriculturalists and agricultural institutions may continue to ignore and resist the changes demanded by the public. In so doing, they risk getting lower levels of financial support and more restrictive policies. Policies that regulate or force restrictions on the agriculture producer when no clear alternatives are present will be destructive. Change must be possible before regulations are put in place to force change. Policies that induce innovation and reward creative research will likely be more successful than regulations in changing agricultural production systems.

The more moderate environmental groups are defining sustainability as long-term workable solutions to the current conflict between agriculture and the environment. These groups seek adjustments within agricultural institutions that will enable agriculture to maintain renewable resources at the current level, avoid wastes beyond the environment's assimilative capacity, and avoid the use of nonrenewable resources while maintaining production efficiency and capacity to ensure a future standard of living at least as high as the current level. Agricultural institutions can improve the chances of survival by seeking assistance from these groups instead of maintaining a rigid and antagonistic posture.

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Book Review

Farming in Nature's Image: An Ecological Approach to Agriculture. 1992. By Judith D. Soule and Jon K. Piper. Island Press, Box 7, Covelo, CA 95428. xix+286 pp. $34.95 hardcover; $19.95 paper.

The theme of this book is Soule and Piper's view of how the science of ecology should be applied to agricultural systems, based on the ideas promoted for the past decade by Wes Jackson, Dana Jackson and The Land Institute (see *New Roots for Agriculture*, University of Nebraska Press, 1980). The authors advocate using structural models of natural ecosystems, many of which are self-perpetuating, as a basis for designing sustainable cropping systems. They emphasize the specific strategy of substituting perennial polycultures for annual crops that currently dominate the former prairie ecosystems of the Great Plains. Although much of the material is at an introductory level, their approach to agroecosystem research should interest anyone involved in sustainable agriculture.

The first two chapters are devoted to convincing the reader of the need for fundamental changes in how agriculture is perceived and conducted in industrial societies. In Chapter 1, the negative environmental consequences of modern agriculture are thoroughly reviewed. An analysis of the reasons we have developed ecologically unsound agricultural practices follows in Chapter 2. The topics covered in this chapter range from the transformation of agriculture to an industrial enterprise (chemicalization, mechanization, and breeding priorities) to how the American cultural values embodied in our economic system have shaped our food system. Soule and Piper comprehensively review the problems associated with agriculture. However, most of this material has been covered in books on sustainable agriculture that have been appearing since the 1970s. The authors acknowledge this in their numerous citations of books and book chapters.

The third chapter is a brief summary of natural ecosystem functions, emphasizing the characteristics that contribute to maintaining the resource base in terrestrial ecosystems. The authors contrast natural ecosystems with agroecosystems, and introduce such concepts as niches, competition, and facilitation. This is an important chapter for those who are not familiar with the field of ecology, because these ideas are the basis for the next two chapters.

At this point, the authors seem unclear about their intended audience. Some material is presented at a very basic level, suitable for an introductory biology course, while other information essential for understanding ecological principles is not covered. Also, this material might be clearer to non-ecologists if the authors had taken a customary textbook approach to ecosystems and communities, rather than using so much agricultural terminology. For example, the discussion of natural ecosystems is from an agricultural, not an ecosystem perspective, as when they say "tilth improves . . . when the amount of organic matter in the soil improves" (p. 97), rather than emphasizing the role of soil organic matter accumulation in promoting successional changes in natural ecosystems.

Not until Chapters 4 and 5 do the authors present their case for an ecosystem approach to agriculture. I found these chapters to be the most interesting and thought-provoking. Chapter 4 begins with the basic premise of The Land Institute: that a sustainable agriculture must be based on native ecosystems as structural models. Soule and Piper highlight the differences between their structural model approach and "process-oriented" approaches, such as reduced tillage, integrated pest management, and intercropping. They point out that although process-oriented solutions often are studied within the context of a cropping system, they do not really constitute a systems approach to sustainability; each addresses just one agricultural problem, and in alleviating that problem may exacerbate others.

In Chapter 5 the authors report on the research in progress at The Land Institute. This work focuses on developing perennial grain and legume crops suitable for polyculture in the soils and climate of the Great Plains. Clearly, this model is in a very early stage of development, and much remains to be done.

The major strength of this book is the authors' unique perspective on agroecology. The idea of blending agriculture and ecology has gained widespread support among sustainable agriculture proponents, particularly in the past few years. In practice, however, this "merging" often involves just piecemeal application of ecological theory to existing cropping systems. The usual question is "How can we modify agricultural systems to enhance ecosystem processes?" In contrast, Soule and Piper begin with the prairie ecosystem and ask "How can we modify this system so it performs an agricultural function yet retains its integrity?" Both approaches are legitimate and necessary if we are to develop sustainable agricultural systems.

The authors' original intent was "to produce a synthesis of ecology and agriculture to be used in classes at The Land Institute and elsewhere." If they had limited the book to that purpose, they would have accomplished a worthy task. Later, however, they modified their goal: "to demonstrate that the economic problems of farmers and rural communities, and the environmental damage resulting from modern agricultural practices, have roots in the industrialization of agriculture." Consequently, their book provides yet another critique of industrial agriculture. As a result, some important concepts are omitted and the discussion of ecosystem functions sometimes is simplistic. They could have presented a stronger case for using ecosystems as models if they had included more specific examples to illustrate the concepts supporting their research. Nevertheless, their book is an important contribution to the sustainable agriculture literature, and is well worth reading.

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References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Use initials only for first and middle names. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized. Page numbers are written out in full (e.g., 1108-1123, not 1108-23). The volume is given if page numbers begin at 1 for each issue.

Citing references

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

Submission of manuscripts

Submit four high-quality copies to Editor, American Journal of Alternative Agriculture, Suite 117, 9200 Edmonston Road, Greenbelt, MD 20770. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form; that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

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A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

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